U. S. DEPARTMENT OF AGRICULTURE

FARMERS' BULLETIN No. 1321

FUMIGATION OF CITRUS TREES FOR CONTROL OF INSECT PESTS

FOR the control of scale insects, growers of citrus fruits in California have for the last 30 years depended upon fumigation of the trees with hydrocyanic-acid gas. A tent is first drawn over the tree and the gas is produced or liberated within the tent. With proper dosage and under proper conditions, the scales are killed and the tree is seldom injured.

Three methods of producing and applying the gas are set forth in this bulletin. The first is the pot method, in which the gas is produced within the tent by adding cyanid to water and sulphuric acid in a glazed earthenware jar. This method some years ago was largely superseded by the fumigating-machine method, in which cyanid solution is added to sulphuric acid and water in a machine mounted on wheels, and the gas is conducted into the tent through a hose. The third method, introduced within the last few years and now very extensively used, is the "liquid gas" method, in which liquid hydrocyanic-acid, carried in a machine, is forced into the tent through a fine nozzle, forming a mist which quickly becomes gas.

Details of these methods, with dosage tables and some necessary cautions, are given in the following pages.

This bulletin supersedes Farmers' Bulletin 923, Fumigation of Citrus Trees.

Washington, D. C. July, 1923

FUMIGATION OF CITRUS TREES FOR CONTROL OF INSECT PESTS.[1]

R. S. Woglum,[2] formerly *Entomologist, Tropical and Subtropical Fruit Insect Investigations, Bureau of Entomology.*

CONTENTS.

WHAT CITRUS FUMIGATION IS.

THE use of hydrocyanic-acid gas in fumigating plants for the destruction of insect pests is one of the most important discoveries in the field of insect control. No other known gas having so wide a range of usefulness so quickly destroys insect life. Its value as a fumigant was discovered in 1886 by the late D. W. Coquillett, an agent of this department, while investigating the control of certain scale insects on citrus trees in California. The success of the gas treatment in that State was immediate and its development rapid, and soon all other methods of controlling citrus scale insects were almost completely supplanted. Nearly every year new sprays have been offered in competition with the gas method, but fumigation has outlived them all and hydrocyanic-acid gas is to-day, even as 30 years ago, by far the most widely used and most effective of all insecticides for scale control on citrus trees on the Pacific coast. In Florida [3] cyanid fumigation has been amply demonstrated several times but never adopted commercially as in California, owing largely to more restrictive climatic conditions. This method of scale control is now used in South Africa, Egypt, Spain, Australia, and Japan.

[1] For a detailed report on fumigation in California see Bulletin 90 of the Bureau of Entomology, United States Department of Agriculture, published in 1911. This may be obtained for 20 cents from the Superintendent of Documents, Government Printing Office, Washington, D. C.

[2] Mr. Woglum resigned from the department September 11, 1920.

[3] Fumigation with wet tents is impracticable because of difficulty of handling as well as of plant injury. In Florida, the normally high humidity, by producing wet tents, seriously restricts fumigation. Short working hours mean higher labor costs and more equipment. Furthermore, the physiological condition of citrus trees under Florida conditions appears to render them more susceptible to cyanid gas injury than under the drier climate of California.

Caution.—*Hydrocyanic-acid gas is colorless and is one of the most deadly poisonous gases known. It has an odor much like that of peach pits. In case of accidental inhalation of the gas, the person affected should be kept in the open air and required to walk to increase respiration.*

The directions given in this bulletin are specifically for the control of scale and related insects infesting citrus trees, although, with proper modification, they will apply to the control of similar insects on other trees and plants.

Orchard fumigation for the control of citrus scale insects consists of covering trees with cloth tents, and liberating hydrocyanic-acid gas beneath these tents. The exposure of the insects to this gas for a definite period, varying with the insects to be controlled, will result in their destruction. In this connection the effect of the gas upon the plants, as well as upon the insects, must be considered.

EQUIPMENT REQUIRED IN ORCHARD TREATMENT.

Orchard fumigation requires special equipment, comprising tents, poles for placing them over the trees, containers for the chemicals, and apparatus for generating the gas.

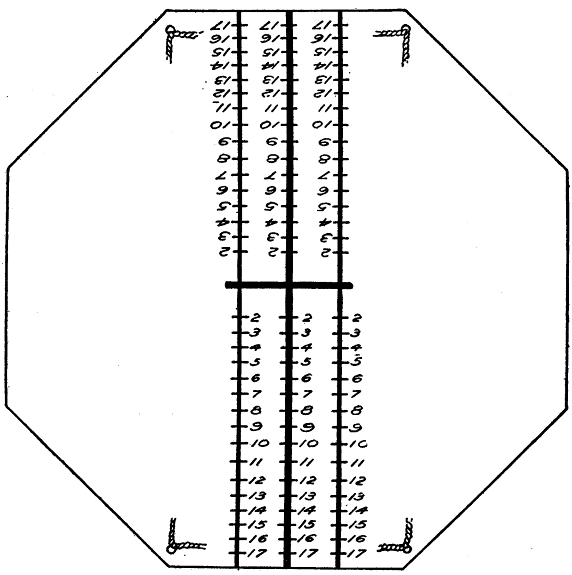


FIG. 1.—Fumigation tent marked according to the Morrill method.

TENTS.

Flat cloth tents of octagonal design (Fig. 1) are employed for orchard fumigation. To avoid waste of cloth in cutting, these tents are constructed of standard sizes based on the distance between parallel sides. The sizes commonly used are 36, 41, 43, 45, 48, 50, 52, 55, 64, 72, and 81 feet.

In purchasing tents the orchardist should be guided by the size of the trees to be fumigated, making due allowance for their normal growth. Tents 36 or 41 feet in size should be used for citrus trees up to 10 feet in height; 41, 43, or 45 foot tents for trees 11 to 15 feet in height; 45, 48, or 52 foot tents for trees 16 to 20 feet in height; and 55, 64, or 72 foot tents for trees 21 to 25 feet in height.

The number of tents required depends largely upon the size of the trees and the acreage to be treated. In California the commercial outfit contains from 15 to 90 tents; the average outfit, however, consists of from 45 to 70 tents 41 to 48 feet in size. The usual length of exposure is one hour, and under the most favorable conditions one tent will cover from 12 to 14 trees a night, though the average for the whole fumigation season approximates from 5 to 7, and the grand

total for the season from 375 to 450, in the case of most commercial outfits. A few outfits which are used over an abnormally long season have exceeded the maximum stated.

MATERIAL.

Material for tents must be of the tightest possible weaves, comparatively light, and of sufficient strength to prevent tearing when trees are being covered. Heavy stiff tents are not only difficult to manipulate but they break branches, injure fruit, and, moreover, will not fit closely to the ground around the trees, thus permitting rapid escape of the gas.

The materials now in general use for sheet tents are 6½-ounce and 7-ounce special drill, 8-ounce double-filled duck, and 7-ounce and 8-ounce special Army duck. A special, closely woven, 8-ounce United States Army duck is recommended as superior to any other cloth for fumigation tents, as it is strong and durable and retains the gas much better than the other grades of cloth.

CONSTRUCTION.

Experienced tent or awning makers are competent to construct these tents.[4] In fact, several firms in this country, particularly in California, specialize in their construction. To secure a tent actually the size required, due allowance must be made for shrinkage of new cloth. For example, a 43-foot tent of new cloth will shrink approximately 3 feet in length and half a foot in width after becoming wet, and other sizes will be reduced proportionately. Some fumigators have their 45-foot tents made 48 feet in length to offset the shrinkage. Large, heavy tents are difficult to manipulate and undesirable, yet neither strength nor lightness should be unduly sacrificed in reducing weight. A method commonly adopted for 40-foot tents or larger is to construct the centers (full strips of equal length) of 8-ounce duck and the "wings" or "skirts" of 7-ounce duck or drill. Duck "skirts" are preferable to drill.

MARKING.

The prevalent system of fumigation requires special marking of the tents. Accurate marking is possible only after the cloth has been shrunk, which is easily accomplished by spreading the tents on a flat, open place where they can be saturated with water. Treatment for mildew, described later, also produces a shrinkage of the cloth. Untreated factory-marked tents require due allowance for shrinkage.

A plan of marking tents that was devised by Dr. A. W. Morrill[5] is shown in Figure 1. Three parallel lines running in the direction of the strips of cloth are graduated at intervals of 1 foot. The middle of each line is considered zero, and the numbering should be outward from this point. The distance between the parallel lines depends on the size of the tent. Three feet has been found to be an appropriate distance for tents up to 45 feet in size, and 4 or 5 feet in larger tents. The middle line should pass through the center of the tent. Where

---

[4] A method of constructing fumigation tents is described in detail in Bulletin 90 of the Bureau of Entomology, United States Department of Agriculture.

[5] Morrill, A. W. Fumigation for the Citrus White Fly as Adapted to Florida Conditions. U. S. Dept. Agr. Bur. Ent. Bul. 76, p. 31. 1908.

many tents are to be marked, a large stencil will facilitate the operation. The numerals should be at least 6 inches in height and can be made with printer's ink, lampblack and turpentine, or a soft, flexible, black paint.

Practice has brought about a modification of the original style of marking, so that to-day the three parallel lines are omitted, merely the figures and dashes, or the figures alone, retained. The figures in the parallel columns should not be the exact counterpart of each other, but each column should be so characterized by a difference in size or shape of numerals, or otherwise, as to enable the tape man readily to distinguish a particular column on opposite sides of a tented tree.

MILDEW PROOFING.

In a dry climate, such as prevails in California, tents are not usually treated to prevent mildew. The life of untreated tents in this climate usually is from four to six years, and depends for the most part upon the extent of their use, the care accorded them, the type of trees covered, and the type of surface soil in the orchards where used. A certain amount of deterioration from mildew has been reported by some fumigators, particularly those operating in the damper coastwise districts, or during the rainy season. Mildew proofing of tents under such conditions would appear advisable. In Florida, as well as in tropical countries where tents become wet every night, treatment to prevent mildew is necessary.

The dipping of tents in a solution of tannin to render them proof against mildew has been done for a long time and is very effective. Tents are dipped in a vat containing hot tannin solution (40 pounds extract of oak bark to about 100 gallons of water) for about 30 minutes and then spread on the ground to dry. Contrary to the usual belief, the tannin treatment does not increase the gas-holding power of the tent, though it appears to increase its wearing quality. A less expensive treatment than tannin, and one which does not change the color of the fabric, consists of sal soda, 5 pounds; tartaric acid, 10 ounces; and zinc sulphate, 5 pounds, to 200 gallons of water. The latter solution has been reported as extensively used in Florida for mildew proofing canvas used for various purposes. Solutions containing copper salts should be avoided, as they are toxic to trees in connection with cyanid gas. The common practice is to dip tents in a large vat. A more expeditious and possible practical method is to spread out a tent on the ground and apply the solution with a power sprayer. After the first tent has been thoroughly saturated, a second can be spread over the first, and this wetted. In this way several tents can be piled one upon the other. The tents should remain in the pile over night to become thoroughly saturated. The next day they can be spread out to dry. The cost of this method should not exceed $1 or $2 a tent. The most convenient time to mildew proof tents is at the close or the beginning of the fumigation season.

GAS PROOFING.

Many efforts have been made in years past to gas proof fumigation tents, but no satisfactory method was found for gas proofing without rendering their use impractical under the rough handling to

which they are subjected in orchard fumigation. During 1921, following experimentation by Prof. H. J. Quayle, of the California Citrus Experiment Station, with a tent made from a discarded Army balloon, there was developed a gas-tight cover made of Army duck uniformly coated on one side with thin rubber. The California Fruit Growers' Exchange put a set of these tents of 48-foot size into the field to determine their commercial value. These tents became permeable to cyanid gas shortly after being placed in the field and the leakage increased with use. The following deductions were made after six months' continuous operation in covering upward of 25,000 trees: (1) The manipulation of gas-tight tents commercially is practicable; (2) tents must be entirely gas tight to be superior to army duck for commercial use; (3) moisture and sunlight restrict field operations with gas-tight tents more than with canvas covers; (4) the injury factor is somewhat magnified with gas-tight covers; (5) the superiority of scale kill or greater uniformity of results was neither proved nor disproved. Of the various materials tried two-ply balloon or balloonet fabric alone was found entirely gas tight, and stood up well during the winter. Hot summer weather, however, broke down the rubber even in this very high-grade cloth. The very considerable experience in California with gas-tight tents would appear to indicate that this type of cover is not likely to displace the present canvas tents for commercial fumigation.

POLES AND DERRICKS.

Either two wooden poles or two derricks are used in placing tents over trees.

The lengths of poles commonly used are 14, 16, or 18 feet. Twenty-foot poles are occasionally used for large trees. These poles average $2\frac{1}{4}$ to $2\frac{1}{2}$ inches in diameter, are rounded, and made of straight-grained, well-seasoned hard pine free from knots. In the Gulf Coast States seasoned cypress is a cheap and satisfactory material for poles. Cypress wood does not need to be milled, as the trees grow straight and slender. It is advisable to have an extra set of poles on hand in case one set is broken. The lower end should be sharpened slightly so that it will hold firmly in the ground, while the upper end, to which a rope is attached for the purpose of erecting the poles, is commonly narrowed bluntly or rounded in accordance with one of the methods suggested in Figure 2.

The sizes of rope most preferred are $\frac{3}{4}$, $\frac{7}{8}$, or 1 inch. Cotton rope has been found easier to handle and more durable than hemp, but the latter is selected by most fumigators because of its lower cost. The rope should be approximately 3 feet longer than the pole. A stout piece of rawhide is sometimes substituted for the first 3 feet of rope adjacent to the pole, as this section, being half hitched over the tent each time the pole is used (see Fig. 21), suffers the most wear.

In covering very tall trees it is necessary to use derricks with uprights about 3 feet higher than the tallest trees. Derricks usually are made of the same material as poles and have a framework attached to the bottom to prevent slipping and to confine the movement to one of two directions when the other end is raised. A rope and pulley arrangement is placed at the top for raising the tent,

and the rope should be approximately three times the length of the pole. The uprights in common use average between 25 and 35 feet in length, with the top $2\frac{1}{2}$ to $3\frac{1}{2}$ inches and the bottom $3\frac{1}{2}$ to $4\frac{1}{2}$ inches in diameter. The construction is shown in Figure 3. The desire for speed has led to the tendency in recent years in California to avoid derricks whenever possible and cover larger trees with poles. Poles 22 and even 24 feet long are now in use. The latest device for covering large trees is to attach a simple pulley to the top of a long pole.

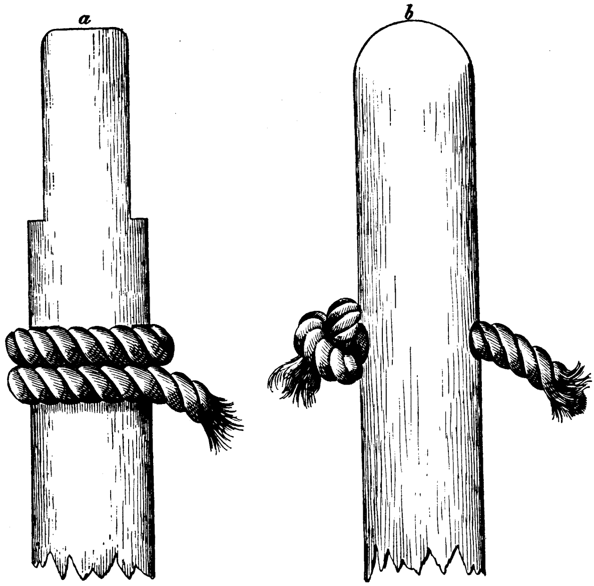


FIG. 2.—Ends of hoisting poles used in placing tents over trees: *a*, Used with tents where rings are present; *b*, used with tents having no rings.

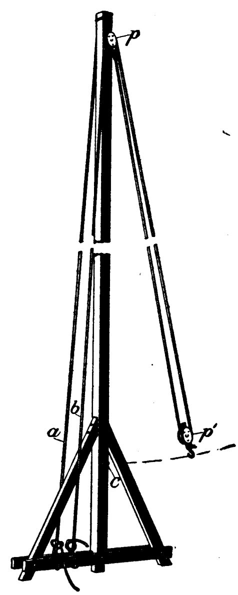


FIG. 3.—A derrick, showing rope and tackle arrangement for raising tents: *a*, Guy rope used in holding derrick in upright position; *b*, pulling rope for raising tent; *p*, upper pulley; *c*, ring to which lower pulley, *p'*, is hooked when not attached to tent.

EQUIPMENT FOR THE POT SYSTEM.

GENERATORS.

Under the pot system of fumigation earthenware vessels, heavily glazed to prevent weakening by action of the acid, are required for generating hydrocyanic-acid gas under the tent. The type of vessel long used in California is shown in Figure 4. Covers are considered a nuisance by many practical fumigators and are seldom used. They are to be recommended, however, as they minimize tent burning, distribute the gas rapidly toward the bottom of the tree, and largely eliminate injury to foliage immediately above the generator. The generator commonly used holds from $1\frac{1}{2}$ to 2 gallons, although a 1-gallon size is used occasionally for small trees and a 3-gallon size for very large trees.

CHEMICAL WAGONS.

An apparatus of some sort is required in orchard work for carrying from tree to tree the chemicals necessary in fumigation. Figure 5 represents a specially equipped cart, which was introduced in California by this depart-

ment in 1908 and which subsequently gained wide usage. Such a cart can be drawn either by the men of the outfit or by a horse. Most fumigators prefer to use a horse-drawn wagon rather than a cart for carrying the chemicals, with the result that a number of very original and ingenious combinations have been devised.

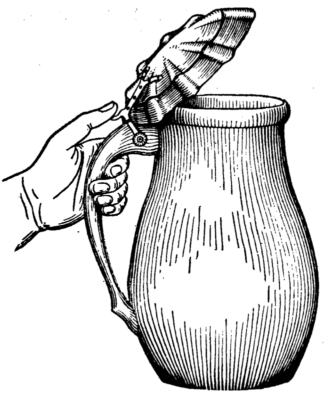


FIG. 4.—A fumigation generator, with cover device.

OTHER EQUIPMENT.

Sulphuric acid comes in large iron drums. A large Stilson or monkey wrench is needed for opening the drum. The acid is easily removed through a special spout or can be siphoned through a hose. As sulphuric acid is very caustic, great care should be exercised in its handling and use. A 1-gallon earthenware or porcelain-lined acid pitcher is needed, and a large lead, copper, or iron funnel. Some fumigators prefer small acid containers in the field and for this purpose use 10-gallon glass carboys in stout wooden frames with handles,

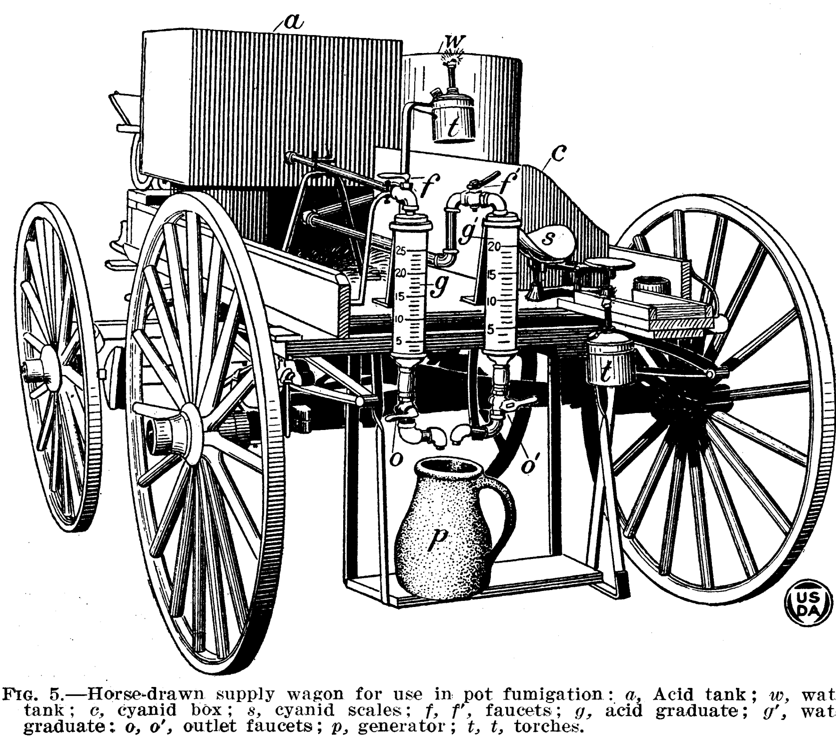


FIG. 5.—Horse-drawn supply wagon for use in pot fumigation: *a*, Acid tank; *w*, water tank; *c*, cyanid box; *s*, cyanid scales; *f*, *f′*, faucets; *g*, acid graduate; *g′*, water graduate; *o*, *o′*, outlet faucets; *p*, generator; *t*, *t*, torches.

as shown in Figure 6, or 2-gallon earthenware jugs. Other necessary apparatus includes a tin-lined cover for cyanid case, barrels for

38787°—23——2

FIG. 6.—Carboy with handles attached to facilitate pouring the acid and carrying the carboy.

water, large water pail, lantern or torch, coal-oil or carbide light or flashlight for tape man, heavy rubber gloves, 50, 66, or 75 feet of tape with special catch for attachment to tent, thermometer, hygrometer, shovel, hatchet, schedule cards of fumigation dosage, blank record sheets, and a large hinged-top wooden box for protecting miscellaneous equipment when not in use.

EQUIPMENT FOR THE MACHINE METHOD.

A large horse-drawn machine for generating cyanid gas outside the tent came into use in 1912 and by 1916 had completely supplanted the pot method of fumigation. The apparatus now

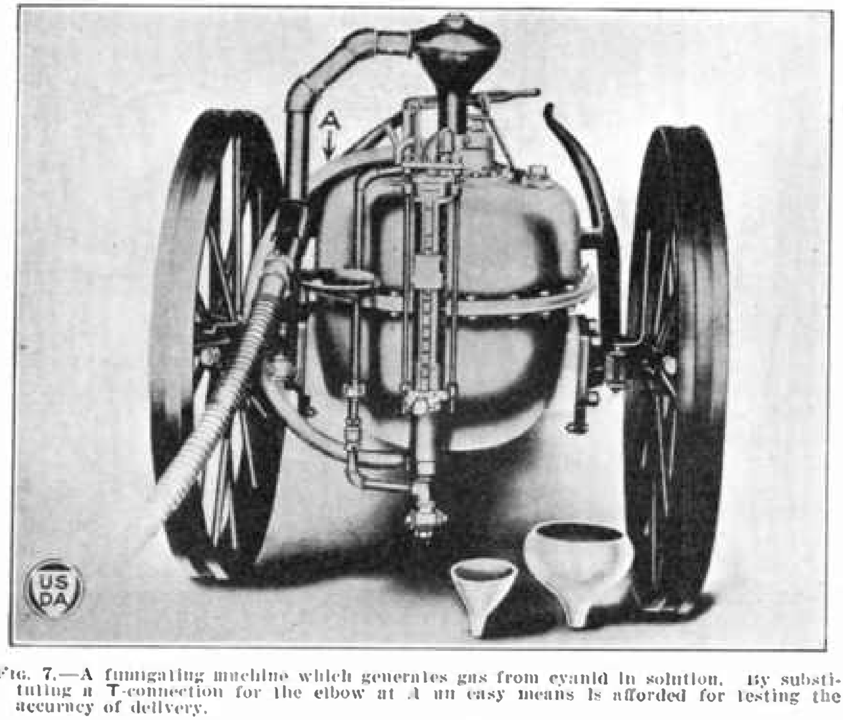


FIG. 7.—A fumigating machine which generates gas from cyanid in solution. By substituting a T-connection for the elbow at A an easy means is afforded for testing the accuracy of delivery.

used in machine generation is illustrated in Figure 7. It consists of two tanks, one above the other, the lower containing a mixture of equal parts of sulphuric acid and water, while the upper contains the cyanid solution. By the action of a suitable pump measured quantities of the cyanid solution are forced into the tank containing the acid-water mixture, and the gas instantly generated escapes to the tented tree through a large hose.

Other equipment needed in machine generation includes cyanid solution tanks (Fig. 8), solution drums, and much of the miscellaneous apparatus listed under the pot system.

EQUIPMENT FOR THE LIQUID HYDROCYANIC-ACID METHOD.

The equipment for liquid hydrocyanic-acid fumigation is decidedly less cumbersome than for either the pot or machine method. Special applicators of 2 or 3 gallons' capacity are used which measure each charge in cubic centimeters, after which it is forcibly ejected through a nozzle and broken into a fine mist beneath the tented tree. Several different applicators have been placed on the market since the introduction of liquid gas. The two types which survived the season of 1921, and proved more accurate than any previously used, are illustrated in Figures 9 and 10.

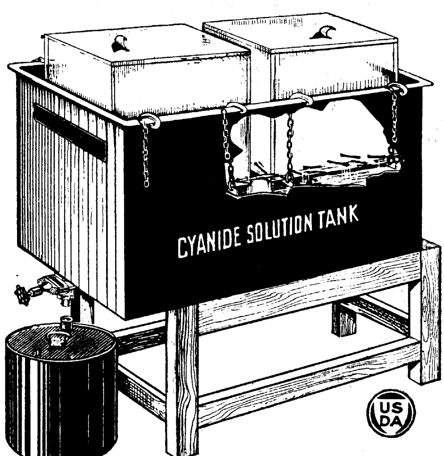


FIG. 8.—Cyanid solution tank for dissolving cyanid to be used in fumigating machines. Below, a 5-gallon field container.

The liquid is delivered in 80 or 100 pound drums. Special faucets are supplied for drawing off the material. A wooden standard is needed for supporting the drum while filling the applicator; insulated drums or containers for holding drums which will afford protection from high temperatures are advocated when liquid gas is held in the field during the daytime. A small amount of miscellaneous equipment is needed and a box for holding it.

CHEMICALS OF FUMIGATION.

Cyanid of sodium or cyanid of potassium, sulphuric acid, and water are necessary for the generation of hydrocyanic-acid gas.

CYANID.[6]

Either sodium cyanid or potassium cyanid in the crystal form can be used in fumigation. Potassium cyanid was used exclusively up

[6] All recommendations made in this bulletin are for sodium cyanid 96 to 99 per cent pure. For the use of potassium cyanid see Bulletin 90 of the Bureau of Entomology, United States Department of Agriculture.

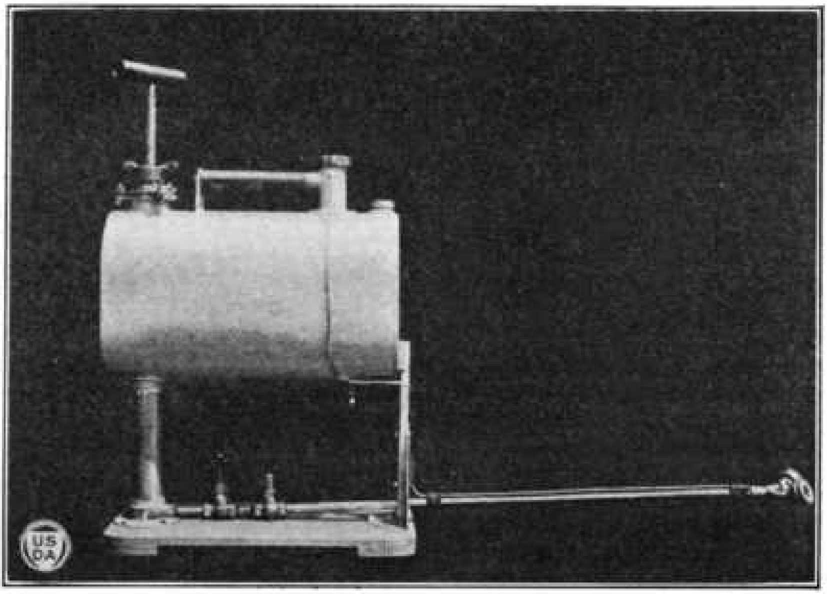


FIG. 9.—A machine for applying liquid hydrocyanic acid beneath tented trees by the movement of a plunger.

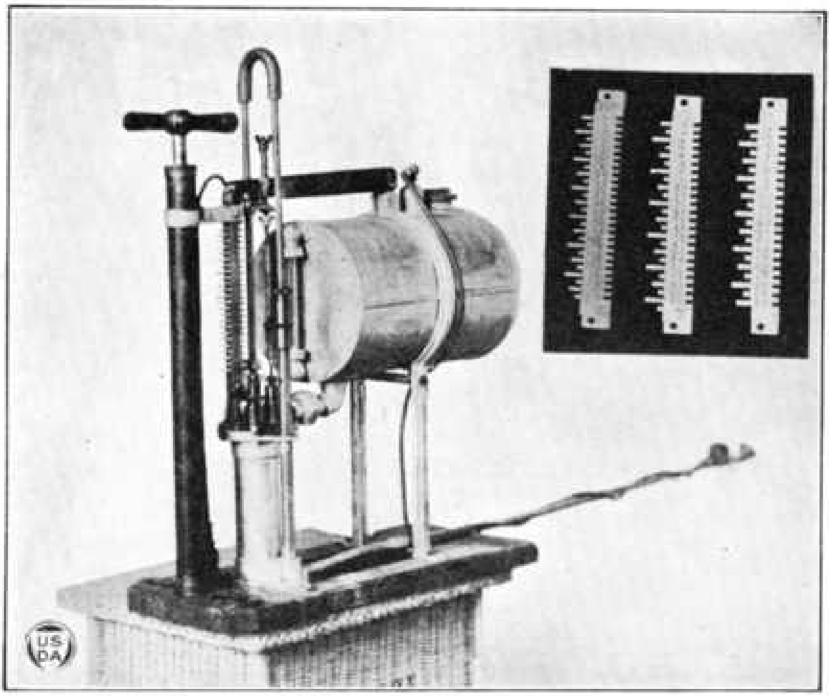


FIG. 10.—A liquid-gas machine introduced in California during 1921. The liquid is forced out of the measuring chamber by air pressure. Inset: Interchangeable gauges which deliver 88, 100, or 111 per cent dosages.

to 1909, but since that date has been superseded by sodium cyanid.[7] Considering the world's limited supply of available potassium salts, there is little likelihood that potassium cyanid will be used again extensively in orchard fumigation.

Sodium cyanid for fumigation purposes should be of 96 to 99 per cent guaranteed purity, thus containing not less than 51 per cent of cyanogen. It should be in large lumps, not finely pulverized. The volume of gas liberated is governed directly by the purity of the cyanid. The dosages for different insects are based on pure cyanid, and poor results are likely to follow if impure chemicals are used. **Too much stress can not be placed on the importance of purchasing high-grade cyanid,** in view of the fact that much of this material on sale by retail druggists is very impure, and thus unsuited for fumigation.

The purchaser will be protected if he obtains a cyanid guaranteed under the insecticide act. The analysis on the label should indicate not less than 51 per cent cyanogen.

Cyanid is decomposed under moist conditions and should be protected from dampness by storage in a tightly covered tin box. If a box of cyanid is to stand for several days without being used, fill the empty space with old cloth or burlap to prevent exposure of the cyanid to air. Unused cyanid at the end of the season's work should be placed in as small a tin as possible and tightly sealed. High-grade cyanid for chemical use can be purchased in cases of 50, 100, or 200 pound sizes.

SULPHURIC ACID.

A commercial sulphuric acid (H_2SO_4) 92 to 94 per cent pure (66° B.), free from nitric acid, arsenic, lead, and zinc, should be used. It does not matter whether the acid is made from pyrites or from pure brimstone, provided impurities are eliminated. Acid is usually purchased in large iron drums holding from 1,500 to 2,000 pounds. It can be purchased also in glass carboys of about 10 gallons capacity. Pure acid is colorless and about twice as heavy as water, its specific gravity being 1.83. If stored in iron drums it frequently has a slightly milky color, especially toward the bottom of the drum. This color is due to sulphate of iron, produced by acid coming in contact with iron either before or after the acid is placed in the drum. This sediment in no way affects the value of the acid, unless it is present in excessive quantities.

Acid may be removed from drums in the field, although it is preferable to convey it thither in 10-gallon glass carboys. Acid will burn the flesh or destroy the clothing quickly, and care should be observed in its handling. Should acid come in contact with the flesh, wash the affected parts quickly with water. The use of rubber gloves in handling the acid containers is advisable.

HOW TO GENERATE HYDROCYANIC-ACID GAS.

THE POT METHOD.

Fumigation with hydrocyanic-acid gas was developed to its present stage of efficiency under the pot method (Fig. 11), the gas being generated in a vessel under a tent by combining cyanid, sulphuric

[7] See Bulletin 90, part 2, of the Bureau of Entomology, page 83.

acid, and water in a glazed earthenware vessel. For each ounce, by weight, of sodium cyanid, 1½ ounces, liquid measure, of sulphuric acid and 2 ounces of water are required to evolve the maximum volume of gas and carry the reaction to completion. This is known as the 1–1½–2 formula. This gives satisfactory results under field conditions, although some fumigators prefer to use 1¼ ounces of sulphuric acid to each ounce of sodium cyanid. For large dosages the latter formula appears quite satisfactory, but in the case of small dosages undissolved cyanid frequently remains and is a cause of complaint.

MIXING THE CHEMICALS.

In mixing the chemicals the water should be measured first and poured into the generator. Next, the acid should be measured and

FIG. 11.—The pot system: Dosing a tree. This view also shows the scheduler securing the measurements of the next tree in the row.

added to the water. This acid-water solution will become very hot. Then the generator should be placed at once beneath the tented tree, well back toward the trunk, and the required amount of cyanid added. The operator can avoid contact with the hydrocyanic-acid gas, which is liberated immediately, by placing the cyanid into the acid-water solution at arm's length. The foregoing procedure should be adhered to closely. **Acid must not be poured into a cyanid-water mixture, as a violent reaction will result.**

The acid-water mixture never should be allowed to cool before the cyanid is added, as a heated solution is necessary for a complete generation of gas. The cyanid should be in lumps averaging about the size of an English walnut, and small pieces should be used only in small dosages. A charge composed entirely of powdered cyanid results in a violent reaction, which is dangerous.

SMALL DOSAGES.

In field fumigation generators of the same size are used frequently with both small and large dosages. In general the results from dosages not exceeding 3 ounces of cyanid are less satisfactory than those from larger dosages, since with the former there is often an incomplete generation of the gas. For the best possible generation there must be enough liquid in the generating vessel to cover the cyanid completely. This is not always accomplished by following the recommended formula with 1-ounce to 3-ounce dosages in flat-bottomed jars unless the cyanid used is in very small pieces and the jar is placed on edge.

Chemical tests have shown that an extra ounce of acid and 2 extra ounces of water added to the quantity required by the formula will give the needed amount of liquid and will in no way affect the liberation of gas in 1, 2, and 3 ounce dosages.

NATURE OF THE RESIDUE.

The residue from the generation of hydrocyanic-acid gas is very poisonous and usually is in the form of a bluish or greenish liquid consisting of water, sulphate of sodium, sulphuric acid, and hydrocyanic acid. Vegetation, such as cover crops, is destroyed by the action of this residue, and even surface roots of citrus trees in loose sandy soil are likely to be injured severely.

Some orchardists demand that the residue be carried off the field, but this precaution is unnecessary in ordinary fumigation where small dosages are used. The residue should never be emptied near the base of a tree, however, but midway between two rows previously fumigated. Care should be exercised that the tents do not come in contact with the residue.

THE MACHINE METHOD.

The pot method of fumigation was almost completely supplanted in 1915 to 1917 through the introduction of portable machines for generating gas outside of the fumigating tent. This development is especially interesting in that it is a return to the principle of generation followed by the late D. W. Coquillett in 1886, when he discovered the efficacy of hydrocyanic-acid gas in the control of insect pests of citrus trees. Mr. Coquillett's procedure consisted in bringing the cyanid dissolved in water in contact with sulphuric acid in a vessel outside the tent, and conducting the resulting gas under the tent by means of a pipe. In 1889 this procedure gave way to the pot method described in foregoing pages.

The first fumigating machine was introduced in 1912, and a second type in 1915. This second type (Figs. 7 and 12) has completely supplanted all other machines.

DISSOLVING THE CYANID.

A heavy sheet-steel or sheet-iron tank is used for dissolving cyanid. (Fig. 8.) The cyanid is purchased in 200-pound containers. Numerous slashes are cut along the lower edge and in the bottom of the

container with a hatchet, and a small opening in the top. The case is then suspended in a tank containing 50 gallons of water, or two cases in 100 gallons of water. Experience has demonstrated that by suspending the cases so that only a small quantity of the cyanid comes in contact with the water, thereby insuring rapid circulation of the water, the cyanid is dissolved rapidly and without agitation. By this method it requires from three to four hours to dissolve a 200-pound case of cyanid.

In the process of dissolving, the saturated solution falls to the bottom of the tank, and unless agitated the solution at the bottom of the tank will be strong and that at the top weak. It is necessary, therefore, that the solution be thoroughly stirred each time as soon as all the cyanid is dissolved and before any solution has been removed from the tanks. Once thoroughly agitated it will remain of a uniform strength throughout for a long time. Cyanid solution deteriorates materially when exposed to direct sunlight, but when it is kept tightly covered in a cool place no deterioration takes place even if allowed to stand for several weeks. Determinations made by the Bureau of Chemistry of this department show that cyanid solution of the concentration of 1 ounce of commercial sodium cyanid to 2 ounces of water will crystallize at a temperature below 50° F. Instances of crystallization at low temperatures have been observed in commercial work. Such crystallization might take place at even a higher temperature in the case of concentrated solution at the bottom of the tank when stirring is neglected. When crystallization occurs the solution should remain unused until redissolved.

The preferred method is to dissolve the cyanid at the warehouse and transport it to the field in drums. If dissolved in the field the solution should be prepared during the day to guarantee complete solution when work is started.

When correctly made (at the rate of 4 pounds of cyanid to 1 gallon of water) the solution has a specific gravity of 1.173 at 80° F. Two hundred pounds of sodium cyanid dissolved in 50 gallons of water (rate of 1 ounce of cyanid to 2 ounces of water) increases the volume to 63 gallons, or about 26 per cent. One gallon of this solution contains about 3.2 pounds of solid sodium cyanid, or 1 pound of cyanid is equal to 0.315 gallon solution. Two and one-half ounces of solution are equal to 1 ounce solid sodium cyanid, and the delivery in the fumigating machine is graduated on this basis.

CHARGING THE MACHINE.

The cyanid solution is poured into the upper reservoir. Charged to full capacity, this holds 12½ gallons, equivalent to 640 ounces of solid sodium cyanid. The amount of acid and water to place in the lower reservoir is determined by the average dosage of the next trees to be fumigated and the number of trees in the row. (A row of thirty 12-ounce trees will require 2¼ gallons of acid and the same quantity of water.) Table 1 gives the calculated dosages of cyanid and acid to meet the requirements of different rows of trees. The water must always be poured into the fumigating machine first. The acid should be added just previous to putting the machine into action so as to get the full benefit of the generated heat.

TABLE 1.—*Ounces of cyanid and gallons of sulphuric acid required by the fumigating machine to fumigate various numbers of different-sized trees.*

TREES PER ROW	AVERAGE DOSE (OUNCES) OF CYANID PER TREE.											
	4	6	8	10	12	14	16	18	20	22	24	26
	TOTAL AMOUNTS OF CYANID AND SULPHURIC ACID REQUIRED.											
24	96 ¾	144 1	192 1¼	240 1½	288 1¾	336 2	384 2¼	432 2¾	480 3	528 3¼	576 3½	624 3¾
26	104 ¾	156 1	208 1¼	260 1½	312 2	364 2¼	416 2½	468 2¾	520 3¼	572 3½	624 3¾	
28	112 ¾	168 1	224 1½	280 1¾	336 2	392 2½	448 2¾	504 3	560 3½	616 3¾		
30	120 ¾	180 1¼	240 1½	300 1¾	360 2¼	420 2½	480 3	540 3¼	600 3¾	660 4		
32	128 ¾	192 1¼	256 1½	320 2	380 2¼	448 2¾	512 3	576 3½	640 3¾			
34	136 1	204 1¼	272 1¾	340 2	408 2½	476 3	544 3¼	612 3¾				
36	144 1	216 1½	288 1¾	360 2¼	432 2¾	504 3	576 3½	648 4				
38	152 1	228 1½	304 2	380 2¼	456 2¾	532 3¼	608 3¾					
40	160 1	240 1½	320 2	400 2½	480 3	560 3½	640 3¾					
42	168 1	252 1½	336 2	420 2½	504 3	588 3½						
44	176 1¼	264 1¾	352 2¼	440 2¾	528 3¼	616 3¾						
46	184 1¼	276 1¾	368 2¼	460 2¾	552 3¼	644 4						
48	192 1¼	288 1¾	384 2¼	480 3	576 3½							
50	200 1¼	300 1¾	400 2½	500 3	600 3½							
52	208 1¼	312 2	416 2½	520 3¼	624 3¾							
54	216 1½	324 2	432 2¾	540 3¼	648 4							
56	224 1½	336 2	448 2¾	560 3¼								
58	232 1½	348 2¼	464 2¾	580 3½								
60	240 1½	360 2¼	480 3	600 3½								

The upper figure in each square indicates the amount of cyanid and the lower figure the amount of concentrated acid required. The proper charge of acid is indicated at the intersection of the columns representing respectively the number of trees per row and the average dose per tree. For example, if a row has thirty-six 10-ounce trees 2¼ gallons of acid would be required. The amount of water used is ALWAYS EQUAL TO THE ACID, AND MUST ALWAYS BE PLACED IN THE MACHINE FIRST.

38787°—23——3

INITIAL CHARGE.

The generating cylinder of a fumigation machine before starting contains a large amount of air which must be displaced before the full charge of cyanid gas is available. Furthermore, the pipe between the pump and acid chamber must be filled with solution before the full charge is recovered. This pipe can be filled by placing the indicator on the 2-ounce mark and operating the pump until solution is forced into the acid chamber. Then generate a 4-ounce charge to displace the air in the chamber and hose. The fumigating machine is then ready for active duty.

OPERATION.

The figures on the solution-pump cylinder represent ounces of solid sodium cyanid, and these correspond to the figures on dosage charts. Each downward stroke of the pump forces a charge of cyanid into the acid reservoir and the chemical reaction and gas delivery are instantaneous, the gas passing through a hose leading to the tented tree. After a row of trees is dosed the residue has become exhausted and should be promptly removed. This residue contains both unused sulphuric acid and cyanid and should be dumped at a distance from the trees to avoid damage. If the machine is cleaned with water at frequent intervals, it will give best results. **Machines should also be tested occasionally so that their accuracy may be assured.**

RESULTS WITH MACHINE FUMIGATION.

Horticultural commissioners, fumigators, and orchardists largely agree that the general results in scale-insect destruction are as satisfactory with the machine method as with the pot system. An investigation of gas generation with the fumigating machine has shown that the average yield of gas with this machine approximates the amount evolved in pot generation.[8]

Nonuniformity of results is at times observed under any system of fumigation. In the case of the fumigating machine it has been most frequently reported that the first tree and the last few trees in the row are not fumigated effectively. This may be obviated, in the case of the first tree, by following the directions given under the heading "Initial charge." Unsatisfactory results on the last few trees indicate exhaustion or cooling of the acid solution toward the end of the row. The supply of acid must be adequate for the cyanid used in that row. A high temperature of the acid solution is best maintained by mixing the acid and water at the last possible moment before starting on the row and by proceeding from tree to tree without delay.

DOSAGE.

The same dosage schedules are used with machines as with pots, and all general recommendations for the procedure, avoidance of plant injury, and insect control are applicable for both pot and machine generation.

---

[8] Young, H. D. The Generation of Hydrocyanic-Acid Gas in Fumigation by Portable Machines. Univ. Calif. Agr. Exp. Sta., Circ. 139, 1915.

MACHINE GENERATION VERSUS POT GENERATION.

The fumigating machine has certain advantages over the pot system. Tent burning is greatly lessened, cumbersome pots are eliminated, the chemicals of fumigation are handled more economically, the residue can be carried from the field, the generator's duties are less burdensome, and one man less is required on an outfit. There are, however, some disadvantages as compared with pots. One point particularly stressed by growers is that with pots the proper amount of chemicals measured out for each individual tree can be seen; whereas with the fumigating machine the improper functioning of the pump valve, which will lessen the dosage for one tree, might lessen the dosage for many successive trees. An irregularity in dosage might arise, also, through failure to dissolve the cyanid thoroughly, or to stir the stratified solution. Cooling of the acid solution sometimes happens in the machine and reduces the amount of gas expelled.

Considering advantages as well as disadvantages under actual operation, there is no doubt that the machine should be preferred to pots. The scale-kill is equally good, most of the disadvantages can be overcome by the careful operator, the fumigating machine is preferred by the fumigator, and the actual cost to the grower will average slightly less than for pot fumigation. The pot method is preferable for the private owner who has only a few trees to be treated, and for the fumigation of house-lot trees and trees in some terraced orchards.

THE LIQUID HYDROCYANIC-ACID METHOD.

The value of liquid hydrocyanic acid (popularly called "liquid gas") for the control of citrus pests was first demonstrated in 1916, and its subsequent history has been most interesting. The method became popular at once with fumigators through the substitution of a light, simplified apparatus (Fig. 13) for the very cumbersome equipment of the pot and fumigating machine systems (Fig. 12) and through the elimination of sulphuric acid in the field. The low degree of purity of the first liquid gas produced commercially retarded its early acceptance by growers, but by 1919 a uniformly high-grade product became available and as a result the liquid-gas method supplanted all others in orchard fumigation in California. When the results of the 1919 season had been studied, however, and it developed that there was much poor work, particularly in certain districts, considerable dissatisfaction arose and some growers returned to former methods. The results of 1920 in several districts were such as to intensify this dissatisfaction, and during 1921 the fumigating machine and pots were again extensively employed, approximately 15 to 20 per cent of all fumigation being done by these two methods.

Dissatisfaction with liquid gas is attributable to various circumstances but the chief fault probably lies in the method of application. The liquid became extensively used before a satisfactory applicator had been developed. The first applicators were more or less erratic in delivery and errors of 10 or even 20 per cent were not uncommon. Heavy cover crops in orchards seriously interfered with full volatili-

zation of the gas expelled as a vapor through nozzles. The same was true of dense foliage, especially on cold, damp nights. There was

FIG. 12.—The equipment used by a fumigating machine outfit.

much daylight fumigation with liquid gas during 1920, which resulted in an abnormal amount of injury. At the same time it was becoming increasingly apparent that the black and red scales in some

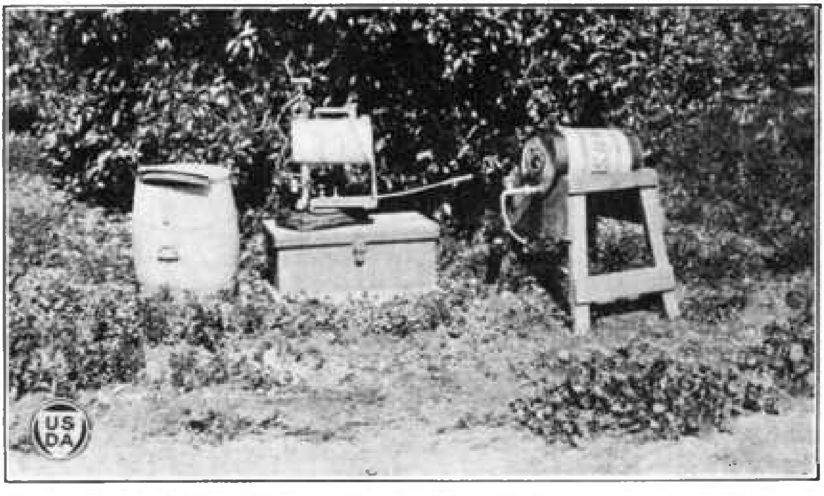


FIG. 13.—Equipment of a liquid-gas outfit, consisting of applicator, drum of gas on wooden standard, insulated container for drum, and wooden chest for miscellaneous articles.

districts were becoming more difficult to kill than in former years. All these conditions caused a retrial of former methods, particularly the pot system.

APPLICATORS.

Liquid hydrocyanic acid is expelled by force through a fine nozzle as a mist which quickly becomes gas. Six different applicators operating on this principle have been developed and used since the introduction of liquid gas for fumigation in California; of these only two (figs. 9 and 10) have fully complied with commercial requirements in accuracy and practicability. The others have been abandoned. These applicators, with the exception of the type shown in Figure 9, all expel the liquid by means of compressed air supplied by a hand pump. They should be tested daily to establish accuracy of delivery. Water should be used for this purpose and can be caught from the nozzles in a funnel can, then measured in a cubic centimeter graduate. A constant and practical check on accuracy will follow the use of a platform scale for weighing the applicator when full before fumigating a row, and again when the row has been fumigated. The difference in weight will indicate the amount used. This can be checked against the actual amount called for by the dosage schedule, and the error of the pump, if any, detected. A rapid method to accomplish this is to add the dosages for the entire row, and then determine the weight for these dosages from Table 2. Suppose the total dosage for the row is 487 units of 16 cubic centimeters and the gas temperature 60° F. From the table, 400 equals 9.96 pounds, 80 equals 1.99 pounds, and 7 equals 0.17 pound, making a total of 12.12 pounds. The weight of the gas used as taken from this scale should closely approximate this total.

TABLE 2.—*Weight in pounds of 97 per cent liquid gas in measured quantities to correspond with the accurate delivery of applicators.*

[Calculations are for liquid gas at 40, 50, 60, or 70° F., when delivered in unit charges of 14, 16, 18, or 20 cubic centimeters.]

Number of unit charges.	40° F.				50° F.			
	14 c. c.	16 c. c.	18 c. c.	20 c. c.	14 c. c.	16 c. c.	18 c. c.	20 c. c.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1	0.02	0.03	0.03	0.03	0.02	0.03	0.03	0.03
2	.04	.05	.06	.06	.04	.05	.06	.06
3	.07	.08	.08	.09	.07	.08	.08	.09
4	.09	.10	.11	.13	.09	.10	.11	.13
5	.11	.13	.14	.16	.11	.13	.14	.16
6	.13	.15	.17	.19	.13	.15	.17	.19
7	.15	.18	.20	.22	.15	.18	.20	.22
8	.18	.20	.23	.25	.18	.20	.23	.25
9	.20	.23	.26	.29	.20	.23	.25	.28
10	.22	.25	.29	.32	.22	.25	.28	.32
20	.44	.51	.57	.64	.44	.50	.57	.63
30	.67	.76	.86	.95	.66	.76	.85	.95
40	.89	1.02	1.14	1.27	.88	1.01	1.13	1.26
50	1.11	1.27	1.43	1.59	1.10	1.26	1.42	1.58
60	1.33	1.52	1.72	1.91	1.32	1.51	1.70	1.89
70	1.56	1.78	2.00	2.23	1.54	1.76	1.98	2.21
80	1.78	2.03	2.29	2.54	1.76	2.02	2.26	2.52
90	2.00	2.29	2.57	2.86	1.98	2.27	2.55	2.84
100	2.23	2.54	2.86	3.18	2.21	2.52	2.83	3.15
200	4.45	5.08	5.72	6.36	4.41	5.04	5.66	6.30
300	6.68	7.62	8.58	9.54	6.62	7.56	8.49	9.45
400	8.90	10.16	11.44	12.72	8.82	10.08	11.32	12.60
500	11.13	12.70	14.30	15.90	11.03	12.60	14.15	15.75
600	13.36	15.24	17.16	19.08	13.23	15.12	16.98	18.90
700	15.58	17.78	20.02	22.26	15.44	17.64	19.81	22.05
800	17.81	20.32	22.88	25.44	17.64	20.16	22.64	25.20
900	20.03	22.86	25.74	28.62	19.85	22.68	25.47	28.35
1,000	22.26	25.40	28.60	31.80	22.05	25.20	28.30	31.50

TABLE 2.—*Weight in pounds of 97 per cent liquid gas in measured quantities to correspond with the accurate delivery of applicators*—Continued.

Number of unit charges.	60° F.				70° F.			
	14 c. c.	16 c. c.	18 c. c.	20 c. c.	14 c. c.	16 c. c.	18 c. c.	20 c. c.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1	0.02	0.02	0.03	0.03	0.02	0.02	0.03	0.03
2	.04	.05	.06	.06	.04	.05	.05	.06
3	.07	.07	.08	.09	.06	.07	.08	.09
4	.09	.10	.11	.12	.08	.10	.11	.12
5	.11	.12	.14	.16	.11	.12	.14	.15
6	.13	.15	.17	.19	.13	.15	.17	.18
7	.15	.17	.20	.22	.15	.17	.19	.21
8	.17	.20	.22	.25	.17	.20	.22	.24
9	.20	.22	.25	.28	.19	.22	.25	.27
10	.22	.25	.28	.31	.21	.25	.28	.30
20	.44	.50	.56	.62	.43	.49	.55	.61
30	.65	.75	.84	.93	.64	.74	.83	.91
40	.87	1.00	1.12	1.24	.85	.99	1.11	1.22
50	1.09	1.25	1.40	1.56	1.07	1.23	1.38	1.52
60	1.31	1.50	1.68	1.87	1.28	1.48	1.66	1.83
70	1.52	1.75	1.96	2.18	1.49	1.73	1.94	2.13
80	1.74	1.99	2.24	2.49	1.71	1.98	2.22	2.44
90	1.96	2.24	2.52	2.80	1.92	2.22	2.49	2.74
100	2.18	2.49	2.80	3.11	2.13	2.47	2.77	3.05
200	4.35	4.98	5.60	6.22	4.27	4.94	5.54	6.10
300	6.53	7.47	8.40	9.33	6.40	7.41	8.31	9.15
400	8.71	9.96	11.20	12.44	8.54	9.88	11.08	12.25
500	10.89	12.45	14.00	15.55	10.67	12.35	13.85	15.25
600	13.06	14.94	16.80	18.66	12.81	14.82	16.62	18.35
700	15.24	17.43	19.60	21.77	14.94	17.29	19.39	21.30
800	17.42	19.92	22.40	24.88	17.08	19.76	22.16	24.40
900	19.59	22.41	25.20	27.99	19.21	22.23	24.93	27.45
1,000	21.77	24.90	28.00	31.10	21.35	24.70	27.70	30.50

Nozzles should be inspected from time to time and kept clean. The nozzle arm should extend from 2 to 2½ feet beyond the tank, and the applicator when in action should be set close against the tent in order that the vaporized liquid may enter the open space surrounding the trunks rather than strike the foliage. The nozzle, however, should not be directed straight toward the trunks, particularly in the case of small trees, where it might cause injury. There should be enough strokes of the pump to insure total expulsion of the gas for each charge.

GENERAL CONSIDERATIONS.

Liquid hydrocyanic acid is supplied in California by two concerns. One produces the liquid from high-grade sodium cyanid, the other from a low-grade sodium-calcium cyanid.[9] The liquid hydrocyanic acid on the market during 1921 carried a guaranty of 96 to 98 per cent purity. This high-grade material is exceedingly volatile in warm, dry air, boiling at a temperature of about 80° F. Pressure sometimes develops at warm temperatures, which necessitates great care in opening drums to avoid sudden expulsion of the contents. Cool storage rooms are a necessity, and most concerns have special houses cooled by ice or a continuous spray of water on the drums. (Fig. 14.) Drums should be taken into the field as late as possible before starting work and covered with wet burlap sacks or placed in insulated containers or other protective device. An excellent plan is for the foreman to take the drums of gas on his way to work in a trailer attached to his automobile (Fig. 14). Direct exposure of drums to

[9] A third concern was recently organized in California to manufacture hydrocyanic acid synthetically.

the sunlight should be avoided. Many citrus trees have been injured by placing drums of gas beneath them. Decomposition of liquid gas was frequent when first produced commercially, but the high-grade liquid gas now supplied can be stored for several months without deterioration.

GAS DIFFUSION.

In the case of pot or machine generation a warm gas is injected beneath the tented tree and rapidly rises toward the top. The gen-

FIG. 14.—Type of house for storage of liquid hydrocyanic acid in California. A continuous spray of water falls over the exposed drums and nets to hold down the temperature. Note the type of trailer with heavily boarded sides for transporting drums and other apparatus between the storage commissary and each field outfit.

eral result is a somewhat better scale kill toward the top than the bottom of the tree. This difference is most noticeable at the cooler temperatures of fumigation. On the other hand, when liquid gas is atomized beneath a tented tree it enters at a very cold temperature. Diffusion is slower than with a warm gas, the concentration becomes greater toward the bottom than the top, and correspondingly the scale kill at the bottom of the tree is superior to that toward the top.[10]

---

[10] Woglum, R. S. Recent results in the fumigation of citrus trees with liquid hydrocyanic acid. *In* Jour. Econ. Ent., v. 12, No. 1, p. 122, 1919.

Temperature appears to exert a considerable influence on gas diffusion, and the popular impression is quite general that on very cold nights little gas rises to the top of large trees. This popular belief does not correspond fully with the results of Federal and State investigations, yet all agree that the scale kill is generally poorer under the liquid gas method at the low temperatures of 36° to 40° F. than at the highest temperatures of fumigation. These inferior results at low temperatures can not be attributed wholly to gas diffusion, for when poor scale kill occurs the condition is evidenced almost equally in all parts of the tree. Rather would it appear traceable to the loss of or the incomplete vaporization of the liquid at low temperatures and also to possible dormancy of the scale.

TEMPERATURE INFLUENCES.

It is the practice of many fumigators to discontinue the use of liquid gas at temperatures below 50° F. Others have adopted 45° as the low temperature limit. No conclusive data are available to show that scale kill at 45° is noticeably inferior to that at 50°, yet the writer advises stopping at 50°. Even when 50° is made the limit the temperature will frequently approach 45° before the tents on the last row are all removed. In fumigating at low temperatures an effort should be made to avoid cover-crop orchards. If the liquid, as it comes from the spray nozzles at cold temperatures, hits an obstruction, such as the cover crop or even the foliage of the citrus tree, it either freezes as ice or condenses as a liquid, which drops to the ground, thereby greatly reducing the strength of the charge.

LIQUID GAS VERSUS POTS AND FUMIGATING MACHINES.

The comparative values of the liquid-gas method, the pot method, and the method using the fumigating machine greatly concern the citrus industry in California at the present time. An unusual amount of dissatisfaction with fumigation results has arisen among growers in recent years. Several districts in which the scale several years ago was more or less successfully fought with a moderate dosage are now experiencing difficulty in controlling the scale with very heavy dosages. When fumigation was then needed only every other year it is now necessary to treat the trees every year and sometimes even twice in the same year. This extreme dissatisfaction with results has culminated since liquid gas was introduced, and, as was natural in such a case, the liquid method has been held in large part responsible for the present situation.

The California Experiment Station and the United States Department of Agriculture have carefully investigated fumigation with liquid gas and agree that if fumigation is conducted at warm temperatures and the work accurately done the results with liquid gas are equally as good as with pots or the fumigating machine. In fact, the results of certain experiments, comparing pot fumigation and that with liquid gas, show that in general the results with liquid gas are more uniform than with pots. The observations of most fumigators and of local horticultural officials who have inspected

much work done commercially by all of these methods lead to the conclusion that liquid gas is as effective in scale kill as either of the other methods, particularly during the regular autumn season.

In cold weather the present method of applying liquid gas appears at times to give somewhat inferior results to the pot or fumigating-machine method. This is due to the loss of material from contact with foliage, etc., whereas with a hot gas there is no loss from this source. An increased dosage might partially offset this loss. An attempt has been made to avoid this inferiority of liquid gas in cold, damp weather by carrying on daylight fumigation during the late fall and winter. Most winter fumigation with liquid gas is now confined to the daytime, when the trees are dry and the air

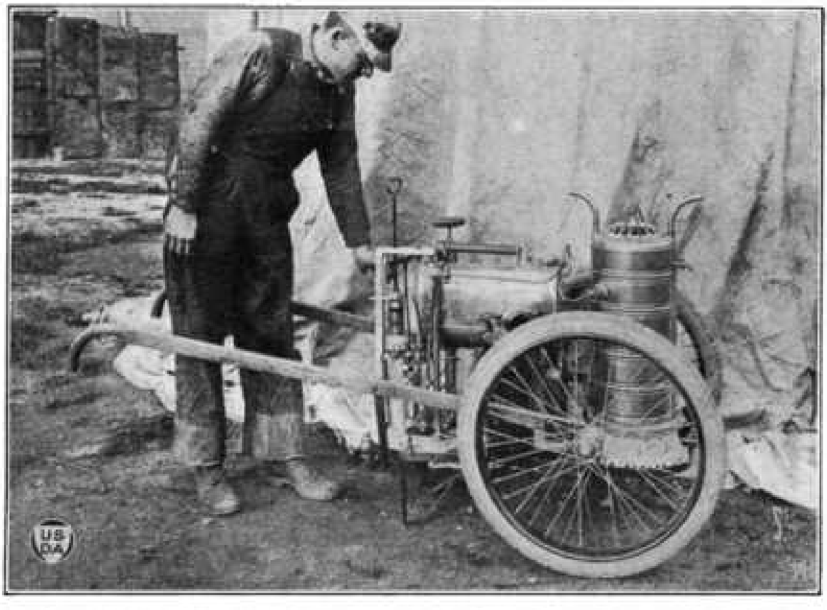


FIG. 15.—A machine for vaporizing liquid hydrocyanic acid, used in California during 1921. The measured liquid is passed through coils of pipe jacketed in hot water. Heat is supplied by a gasoline burner. Gasification is immediate.

warm. This particular inferiority of liquid gas arises not from the material itself but from the method of application. The writer is fully convinced that the present outstanding need of the liquid-gas system is a practical apparatus which will convert the liquid to gas before it enters the tent, and that the liquid-gas method will not completely supplant the other methods until the principle of atomizing is superseded by one of complete gasification. Machines which will vaporize liquid gas have been constructed. One type of vaporizer (Fig. 15) was tried by several fumigators, including the writer, during the season of 1921, but failed to give complete satisfaction, chiefly because of small capacity and lack of dependability. This work, however, did prove that liquid hydrocyanic acid can be safely gasified in the field by heat, and it should be only a matter

38787°—23——4

of time before a thoroughly practical and perfected machine for this purpose will be developed; in fact, an important advance in this direction appears already to have been made in the machine shown in Figure 16, which was introduced during the season of 1922. Other vaporizers are in course of development.[11]

PROPERTIES OF LIQUID GAS.

Very little has been published on liquid hydrocyanic acid, and data of value in connection with the use of this material are for the

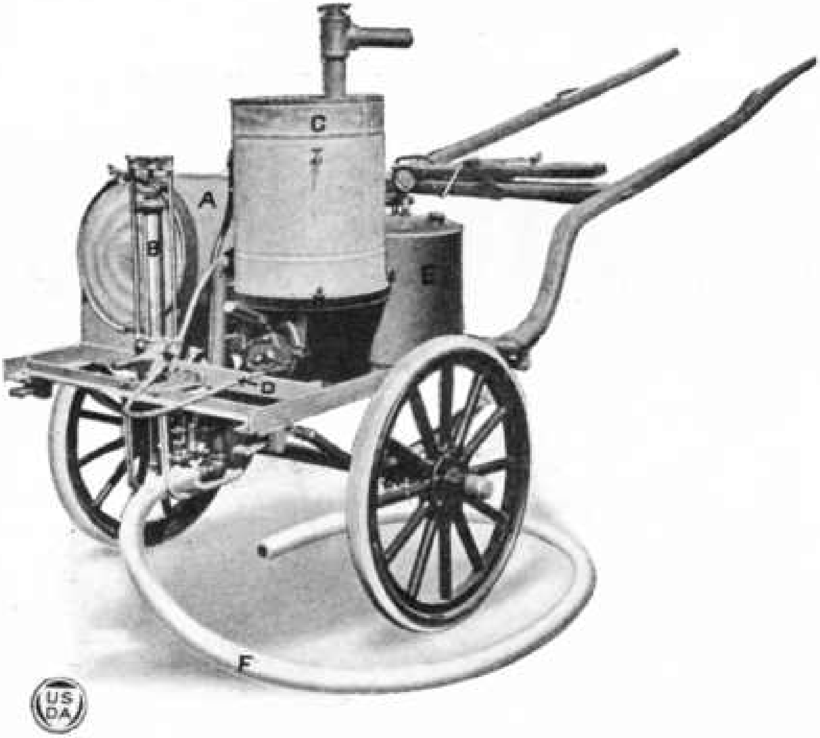


FIG. 16.—A horse-drawn vaporizing machine introduced during 1922. The liquid gas is used directly from field drums, *A*. The principle of vaporization was adapted from the machine shown in Figure 15. *B*, Measuring apparatus; *C*, hot-water jacket; *D*, gasoline feed to burner; *E*, gasoline tank; *F*, outlet hose for cyanid gas.

most part not readily accessible. A few data needed by fumigators are presented in Tables 3, 4, and 5.

---

[11] Since preparing the manuscript of this bulletin a vaporizer of unique design and practical merit has been introduced and successfully tried. This vaporizer is illustrated in Figure 17. The apparatus is so arranged on a platform that it can be mounted intact on an automobile chassis and the machine operated from the rear platform. The very interesting part of this apparatus is that the exhaust gas from the motor, mixed with air, is passed into a burner, and the combustible mixture reignited. It is stated that a temperature of approximately 1450° F. is generated within the stove. A metal coil is located within the stove. As each charge of fumigant is forced into this coil it instantly vaporizes into gas and is discharged through a tube beneath the tented tree at a very high temperature. The manufacturer of this machine recommends a mixture of liquid hydrocyanic acid and water rather than the 96 to 98 per cent material commonly used, maintaining that a hot, moist gas promises a quick uniformity of distribution within the tented inclosure. The machine has changeable measuring devices for different schedules. Special safety containers form a part of this equipment. By removing the special platform, after the fumigation season is over, the chassis is left in its original state, available for general use.

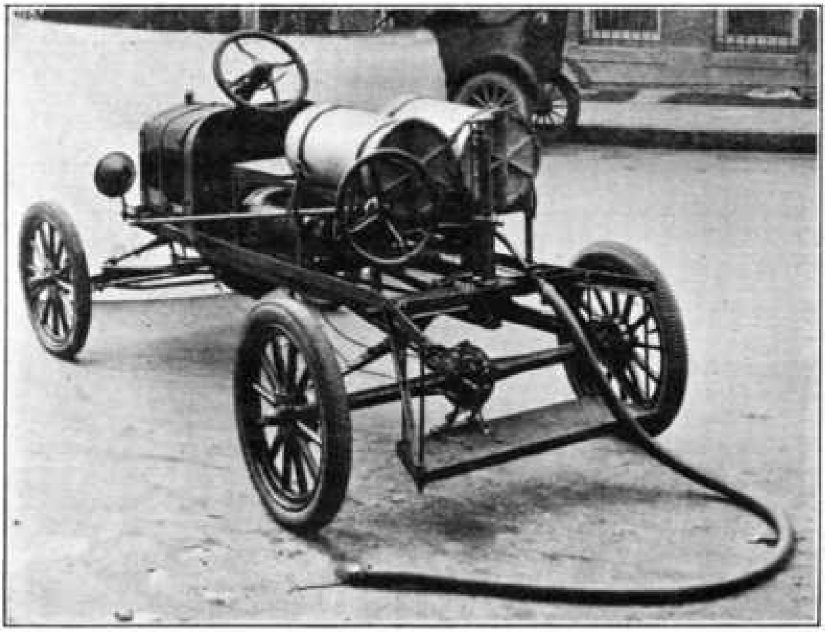


FIG. 17.—A special machine for vaporizing liquid hydrocyanic acid. The apparatus is so arranged on a platform that it can be mounted intact on an automobile chassis. An intense heat for vaporizing the liquid fumigant results from burning a mixture of the exhaust gas of the motor and air. The operator handles the apparatus and drives the automobile from the rear platform.

TABLE 3.—*Properties of liquid hydrocyanic acid.*[1]

WEIGHT OF 1 GALLON AT 60° F.

Per cent purity.	Weight in pounds.
99	5.828
98	5.855
97	5.883
96	5.911
95	5.939

VOLUME OF 1 POUND OF 96 AND 98 PER CENT HYDROCYANIC ACID AT TEMPERATURES FROM 40° TO 79° F.

°F.	96 per cent (cubic centimeters).	98 per cent (cubic centimeters).
40	626	632
50	633	639
60	639	645
70	646	652
79	653	659

POUNDS OF 98 PER CENT HYDROCYANIC ACID REQUIRED TO FUMIGATE 100 TREES, USING UNIT CHARGES OF 18 CUBIC CENTIMETERS.

[1 pound 98 per cent hydrocyanic acid (60° F.) contains 36 18-cubic-centimeter unit charges.]

	Pounds.
100 8-charge trees	22.25
100 10-charge trees	27.8
100 16-charge trees	44.5

[1] One gallon of water weighs 8.329 pounds.

TABLE 3.—*Properties of liquid hydrocyanic acid*—Continued.

COMPARISON OF GAS FROM POT GENERATION WITH EQUIVALENT IN LIQUID GAS.

[Based on chemical determinations.]

1 ounce of 97 per cent sodium cyanid 93 per cent gas generation equals 20.44 cubic centimeters liquid gas 98 per cent at 60° F.
1 ounce of 98 per cent potassium cyanid 93 per cent gas generation equals 15.54 cubic centimeters liquid gas 98 per cent at 60° F.

CYANID EQUIVALENTS IN LIQUID GAS AS BASED ON FIELD RESULTS IN SCALE CONTROL.[2]

1 ounce of 97 per cent sodium cyanid is equivalent to 18 cubic centimeters 96 per cent to 98 per cent liquid gas.
1 pound of 96 per cent to 98 per cent liquid gas is equivalent to 2¼ pounds 97 per cent sodium cyanid.

TABLE 4.—*Specific gravity table for determining the percentage of liquid hydrocyanic acid at different temperatures.*[1]

Observed specific gravity.	Observed temperature in degrees Fahrenheit.																				
	70	69	68	67	66	65	64	63	62	61	60	59	58	57	56	55	54	53	52	51	50
	Percentage of liquid hydrocyanic acid.																				
0.695	98.1	98.4	98.6	98.8	99.0	99.3	99.5	99.7	....	....	....	....	....	....	....	....	....	....	....	....	....
0.696	97.8	98.1	98.3	98.5	98.7	99.0	99.2	99.4	99.6	....	....	....	....	....	....	....	....	....	....	....	....
0.697	97.5	97.8	98.0	98.2	98.4	98.7	98.9	99.1	99.3	99.6	99.8	....	....	....	....	....	....	....	....	....	....
0.698	97.2	97.5	97.7	97.9	98.1	98.4	98.6	98.8	99.0	99.3	99.5	99.7	99.9	....	....	....	....	....	....	....	....
0.699	96.9	97.2	97.4	97.6	97.8	98.1	98.3	98.5	98.7	99.0	99.2	99.4	99.6	99.8	....	....	....	....	....	....	....
0.700	96.6	96.9	97.1	97.3	97.5	97.8	98.0	98.2	98.4	98.7	98.9	99.1	99.3	99.5	99.7	....	....	....	....	....	....
0.701	96.3	96.6	96.8	97.0	97.2	97.5	97.7	97.9	98.1	98.4	98.6	98.8	99.0	99.2	99.4	99.6	99.8	....	....	....	....
0.702	96.0	96.3	96.5	96.7	96.9	97.2	97.4	97.6	97.8	98.1	98.3	98.5	98.7	98.9	99.1	99.3	99.5	99.8	....	....	....
0.703	95.7	96.0	96.2	96.4	96.6	96.9	97.1	97.3	97.5	97.8	98.0	98.2	98.4	98.6	98.8	99.0	99.3	99.5	99.8	....	....
0.704	95.4	95.7	95.9	96.1	96.3	96.6	96.8	97.0	97.2	97.5	97.7	97.9	98.1	98.4	98.6	98.8	99.0	99.2	99.5	99.7	99.9
0.705	95.1	95.4	95.6	95.8	96.0	96.3	96.5	96.7	96.9	97.2	97.4	97.6	97.8	98.1	98.3	98.5	98.7	98.9	99.2	99.4	99.6
0.706	94.8	95.1	95.3	95.5	95.7	96.0	96.2	96.4	96.6	96.9	97.1	97.3	97.5	97.8	98.0	98.2	98.4	98.6	98.9	99.1	99.3
0.707	94.5	94.8	95.0	95.2	95.4	95.7	95.9	96.1	96.3	96.6	96.8	97.0	97.2	97.5	97.7	97.9	98.1	98.3	98.6	98.8	99.0
0.708	94.2	94.5	94.7	94.9	95.1	95.4	95.6	95.8	96.0	96.3	96.5	96.7	96.9	97.2	97.4	97.6	97.8	98.0	98.3	98.5	98.7
0.709	93.9	94.2	94.4	94.6	94.8	95.1	95.3	95.5	95.7	96.0	96.2	96.4	96.6	96.9	97.1	97.3	97.5	97.7	98.0	98.2	98.4
0.710	93.6	93.9	94.1	94.3	94.5	94.8	95.0	95.2	95.4	95.7	95.9	96.1	96.3	96.6	96.8	97.0	97.2	97.4	97.7	97.9	98.1
0.711	93.3	93.6	93.8	94.0	94.2	94.5	94.7	94.9	95.1	95.4	95.6	95.8	96.0	96.3	96.5	96.7	96.9	97.1	97.4	97.6	97.8
0.712	93.0	93.3	93.5	93.7	93.9	94.2	94.4	94.6	94.8	95.1	95.3	95.5	95.7	96.0	96.2	96.4	96.6	96.8	97.1	97.3	97.5
0.713	92.7	93.0	93.2	93.4	93.6	93.9	94.1	94.3	94.5	94.8	95.0	95.2	95.4	95.7	95.9	96.1	96.3	96.5	96.8	97.0	97.2
0.714	92.4	92.7	92.9	93.1	93.3	93.6	93.8	94.0	94.2	94.5	94.7	94.9	95.1	95.4	95.6	95.8	96.0	96.2	96.5	96.7	96.9
0.715	92.1	92.4	92.6	92.8	93.0	93.3	93.5	93.7	93.9	94.2	94.4	94.6	94.8	95.1	95.3	95.5	95.7	95.9	96.2	96.4	96.6

[1] Prepared by Prof. E. R. Hulbirt.
[2] Woglum, R. S. A dosage schedule for citrus fumigation with liquid hydrocyanic acid. *In* Journ. Econ. Ent., v. 12, no. 5, p. 357–363, 1919.

TABLE 5.—*Table for calculating the amount of liquid hydrocyanic acid (97 per cent), in pounds, required to fumigate different numbers of 2 to 60 charge trees with 16, 18, or 20-cubic-centimeter units (88, 100, or 111 per cent schedules).*

Charges per tree.	Number of trees.																																
	10			15			20			25			30			35			40			45			50			60			70		
	Dosage schedule and size of unit charge.																																
	88 %	100 %	111 %	88 %	100 %	111 %	88 %	100 %	111 %	88 %	100 %	111 %	88 %	100 %	111 %	88 %	100 %	111 %	88 %	100 %	111 %	88 %	100 %	111 %	88 %	100 %	111 %	88 %	100 %	111 %	88 %	100 %	111 %
	16 c. c.	18 c. c.	20 c. c.	16 c. c.	18 c. c.	20 c. c.	16 c. c.	18 c. c.	20 c. c.	16 c. c.	18 c. c.	20 c. c.	16 c. c.	18 c. c.	20 c. c.	16 c. c.	18 c. c.	20 c. c.	16 c. c.	18 c. c.	20 c. c.	16 c. c.	18 c. c.	20 c. c.	16 c. c.	18 c. c.	20 c. c.	16 c. c.	18 c. c.	20 c. c.	16 c. c.	18 c. c.	20 c. c.
	Pounds of liquid hydrocyanic acid required.																																
2	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.5	1.5	1.5	1.5	2.0	1.5	2.0	2.0	2.0	2.0	2.5	2.0	2.5	2.5	2.5	3.0	3.0	2.5	3.0	3.5	3.0	3.5	4.0	3.5	4.0	4.5
4	1.0	1.5	1.5	1.5	2.0	2.0	2.0	2.5	2.5	2.5	3.0	3.5	3.0	3.5	4.0	3.5	4.0	4.5	4.0	4.5	5.0	4.5	5.5	6.0	5.0	6.0	6.5	6.0	7.0	7.5	7.0	8.0	9.0
6	1.5	2.0	2.0	2.5	3.0	3.0	3.0	3.5	4.0	4.0	4.5	5.0	4.5	5.5	6.0	5.5	6.0	7.0	6.0	7.0	7.5	7.0	8.0	8.5	7.5	8.5	9.5	9.0	10.5	11.5	10.5	12.0	13.5
8	2.0	2.5	2.5	3.0	3.5	4.0	4.0	4.5	5.0	5.0	6.0	6.5	6.0	7.0	7.5	7.0	8.0	9.0	8.0	9.0	10.0	9.0	10.5	11.5	10.0	11.5	12.5	12.0	13.5	15.0	14.0	16.0	17.5
10	2.5	3.0	3.5	4.0	4.5	5.0	5.0	6.0	6.5	6.5	7.0	8.0	7.5	8.5	9.5	9.0	10.0	11.0	10.0	11.5	12.5	11.5	13.0	14.0	12.5	14.0	16.0	15.0	17.0	19.0	17.5	20.0	22.0
12	3.0	3.5	4.0	4.5	5.5	6.0	6.0	7.0	7.5	7.5	8.5	9.5	9.0	10.5	11.5	10.5	12.0	13.0	12.0	13.5	15.0	13.5	15.5	17.0	15.0	17.0	19.0	18.0	20.5	22.5	21.0	24.0	26.5
14	3.5	4.0	4.5	5.5	6.0	7.0	7.0	8.0	9.0	9.0	10.0	11.0	10.5	12.0	13.5	12.5	14.0	15.5	14.0	16.0	17.5	16.0	18.0	20.0	17.5	20.0	22.0	21.0	24.0	26.5	24.5	27.5	30.5
16	4.0	4.5	5.0	6.0	7.0	7.5	8.0	9.0	10.0	10.0	11.5	12.5	12.0	13.5	15.0	14.0	16.0	17.5	16.0	18.0	20.0	18.0	20.5	22.5	20.0	22.5	25.0	24.0	27.0	30.0	28.0	31.5	35.0
18	4.5	5.5	6.0	7.0	8.0	8.5	9.0	10.5	11.5	11.5	13.0	14.0	13.5	15.5	17.0	16.0	18.0	20.0	18.0	20.5	22.5	20.5	23.0	25.5	22.5	25.5	28.0	27.0	30.5	34.0	31.5	35.5	39.5
20	5.0	6.0	6.5	7.5	8.5	9.5	10.0	11.5	12.5	12.5	14.0	16.0	15.0	17.0	19.0	17.5	20.0	22.0	20.0	22.5	25.0	22.5	25.5	28.0	25.0	28.0	31.5	30.0	34.0	37.5	35.0	39.5	44.0
22	5.5	6.5	7.0	8.5	9.5	10.5	11.0	12.5	14.0	14.0	15.5	17.5	16.5	18.5	21.0	19.5	22.0	24.0	22.0	25.0	27.5	25.0	28.0	31.0	27.5	31.0	34.5	33.0	37.0	41.0	38.5	43.5	48.0
24	6.0	7.0	7.5	9.0	10.5	11.5	12.0	13.5	15.0	15.0	17.0	19.0	18.0	20.5	22.5	21.0	24.0	26.5	24.0	27.0	30.0	27.0	30.5	34.0	30.0	34.0	37.5	36.0	40.5	45.0	42.0	47.5	52.5
26	6.5	7.5	8.5	10.0	11.0	12.5	13.0	15.0	16.5	16.5	18.5	20.5	19.5	22.0	24.5	23.0	25.5	28.5	26.0	29.5	32.5	29.5	33.0	36.5	32.5	36.5	40.5	39.0	44.0	48.5	45.5	51.0	57.0
28	7.0	8.0	9.0	10.5	12.0	13.5	14.0	16.0	17.5	17.5	20.0	22.0	21.0	24.0	26.5	24.5	27.5	30.5	28.0	31.5	35.0	31.5	35.5	39.5	35.0	39.5	43.5	42.0	47.5	52.5	49.0	55.0	61.0
30	7.5	8.5	9.5	11.5	13.0	14.0	15.0	17.0	19.0	19.0	21.0	23.5	22.5	25.5	28.0	26.5	29.5	33.0	30.0	34.0	37.5	34.0	38.0	42.0	37.5	42.0	47.0	45.0	50.5	56.0	52.5	59.0	65.5
32	8.0	9.0	10.0	12.0	13.5	15.0	16.0	18.0	20.0	20.0	22.5	25.0	24.0	27.0	30.0	28.0	31.5	35.0	32.0	36.0	40.0	36.0	40.5	45.0	40.0	45.0	50.0	48.0	54.0	60.0	56.0	63.0	70.0
34	8.5	10.0	11.0	13.0	14.5	16.0	17.0	19.5	21.5	21.5	24.0	26.5	25.5	29.0	32.0	30.0	33.5	37.5	34.0	38.5	42.5	38.5	43.0	48.0	42.5	48.0	53.0	51.0	57.5	63.5	59.5	67.0	74.5
36	9.0	10.5	11.5	13.5	15.5	17.0	18.0	20.5	22.5	22.5	25.5	28.0	27.0	30.5	34.0	31.5	35.5	39.5	36.0	40.5	45.0	40.5	45.5	50.5	45.0	50.5	56.0	54.0	60.5	67.5	63.0	71.0	78.5
38	9.5	11.0	12.0	14.5	16.0	18.0	19.0	21.5	24.0	24.0	27.0	30.0	28.5	32.0	35.5	33.5	37.5	41.5	38.0	43.0	47.5	43.0	48.0	53.5	47.5	53.5	59.5	57.0	64.0	71.0	66.5	74.5	83.0
40	10.0	11.5	12.5	15.0	17.0	19.0	20.0	22.5	25.0	25.0	28.0	31.5	30.0	34.0	37.5	35.0	39.5	44.0	40.0	45.0	50.0	45.0	50.5	56.0	50.0	56.0	62.5	60.0	67.5	75.0	70.0	78.5	87.5
50	12.5	14.0	16.0	19.0	21.0	23.5	25.0	28.0	31.5	31.5	35.0	39.0	37.5	42.0	47.0	44.0	49.0	54.5	50.0	56.0	62.5	56.5	63.0	70.0	62.5	70.0	78.0	75.0	84.0	93.5	87.5	98.0	109.0
60	15.0	17.0	19.0	22.5	25.5	28.0	30.0	34.0	37.5	37.5	42.0	47.0	45.0	50.5	56.0	52.5	59.0	65.5	60.0	67.5	75.0	67.5	76.0	84.0	75.0	84.0	93.5	90.0	101.0	112.0	105.0	118.0	131.0

DOSAGE SCHEDULES.[12]

The term "dosage" is used to indicate the amount of cyanid needed to destroy a particular insect, and varies with the size of the tree. Since a definite amount of gas is generated from an ounce of cyanid, the ounce has been established as the unit of dosage for the pot and fumigating machine. In the case of the latter the cyanid is in solution, but the measuring pump is so graduated that each unit represents 1 ounce of solid sodium cyanid.

Several years of experimental work in California, during which thousands of trees have been treated for the control of different

DISTANCE AROUND IN FEET

DISTANCE OVER IN FEET

	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48		50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
10	2	2	3	3	3															10																10
12	3	3	3	4	4	4	4													12																12
14	3	3	4	4	4	4	5	5												14																14
16	4	4	4	4	5	5	5	5	5	5	5	6								16																16
18	4	4	4	5	5	5	5	5	6	6	6	6	6							18																18
20			4	5	5	5	6	6	6	6	7	7	7	7	7	7	7			20																20
22					5	6	6	6	7	7	7	7	7	8	8	8	8	8		22																22
24					6	6	6	7	7	7	7	8	8	8	8	8	9	9	9	24																24
26								7	7	8	8	8	8	9	9	9	9	9	10	26	10															26
28									8	8	8	9	9	9	9	10	10	10	10	28	11	11	11													28
	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48		50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
30										8	9	9	9	10	10	10	11	11	11	30	12	12	12	12	13	13										30
32											9	9	10	10	11	11	12	12	12	32	13	13	13	14	14	14	15									32
34												10	10	11	12	12	13	13	13	34	14	14	14	15	15	15	16	16								34
36												10	11	12	12	13	13	14	14	36	15	15	16	16	16	16	17	17								36
38													12	12	13	14	14	15	15	38	16	16	17	17	17	18	18	18	19							38
40																14	15	16	16	40	17	17	18	18	18	19	19	19	20	20	21					40
42																	16	17	17	42	18	18	19	19	20	20	20	21	21	22	22	22				42
44																		17	18	44	19	19	20	20	21	21	21	22	22	22	23	23	24			44
46																				46	20	20	21	21	22	22	23	23	23	24	24	24	25	25	26	46
48																				48	20	21	22	22	23	23	24	24	25	25	25	26	26	27	27	48
	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48		50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
50																				50	21	22	23	23	24	24	25	25	26	26	27	27	28	28	29	50
52																				52				24	25	25	26	26	27	27	28	28	29	30	30	52
54																				54					25	26	27	28	28	29	29	30	31	31	32	54
56																				56						27	28	28	29	30	31	31	32	33	33	56
58																				58						28	28	29	30	31	32	33	33	34	34	58

FIG. 18.—Dosage Schedule No. 1 (100 per cent), for pot or fumigating machine, for sodium cyanid 96–99 per cent (containing not less than 51.3 per cent cyanogen). Dosages are in ounces. (Revised form.)

scale insects, have made it possible to calculate dosages for different-sized trees and to prepare tables in convenient form for rapid use in the field. These dosages are based on actual results under practical field conditions, proper consideration being given to the important subject of leakage.

One table prepared by this department has formed the basis for fumigation dosage in California since 1908. Fumigators, however, have felt that the dosages for small trees as given on this schedule

[12] In previous writings the author has referred to high-grade sodium cyanid as being 126 to 130 per cent pure. An equal amount by weight of chemically pure sodium cyanid liberates 33 per cent more hydrocyanic-acid gas than does pure potassium cyanid; and as potassium cyanid was the chemical formerly used for generating hydrocyanic-acid gas, this was expressed by designating the pure sodium cyanid as 133 per cent. In this bulletin where sodium cyanid is mentioned as 96 to 99 per cent pure, or containing not less than 51 per cent of cyanogen, it is of the same strength as that termed in former writings "126 to 130 per cent pure." Likewise Dosage Schedule 1 for sodium cyanid 96 to 99 per cent pure, containing not less than 51 per cent of cyanogen, is the same schedule as that formerly termed "Dosage Schedule 1" for sodium cyanid 126 to 130 per cent pure.

were a little too low, and in recent years this has led to the practice of slightly increasing the dosages for trees of this size. The old schedule has therefore been revised and the revised form is shown in Figure 18.

The dosage for a tree is determined by two measurements taken after the tree is covered with a tent. These are the distance in feet around the tent at a height of about 3 feet from the ground and the distance in feet over the top of the tent from ground to ground. The numbers indicating the size of the tree are arranged along the outer sides of the chart. The square in the chart, formed by the intersection of the lines running from the two numbers representing, respectively, the distance around and the distance over a tree, contains the dosage for a tree of this size. For example, if it is found that the distance over the tent is 30 feet and the distance around the tent is 42 feet, the intersection of the lines leading from these numbers indicates that 10 ounces of sodium cyanid is the amount required by a tree of that size with Dosage Schedule No. 1. (See Fig. 18.) Using the 1–1½–2 formula for sodium cyanid in pot generation, 15 ounces of sulphuric acid and 20 ounces of water would be required for this charge. For the fumigating machine the plunger is raised to 10 and then lowered in order to discharge the proper amount of solution.

Dosage Schedule No. 1, sometimes called the 100 per cent or full schedule, gives a somewhat concentrated gas—a gas stronger than every condition demands. To meet this demand for lighter dosage a schedule of dosages three-fourths or 75 per cent as strong as Schedule No. 1 may be used. Some fumigators use an 85 per cent dosage schedule calculated from Schedule No. 1; others use schedules giving a more concentrated gas, as 110, 125, or even 150 per cent.

The introduction of liquid gas led to a partial revision in dosage procedure and the establishment of a new unit of measurement. Investigations of this department[13] developed that under field conditions 18 cubic centimeters of high-grade liquid hydrocyanic acid (95 to 98 per cent) produced results in scale kill equivalent to those of 1 ounce of high-grade sodium cyanid. Accordingly, 18 cubic centimeters was adopted as the unit of measurement for liquid hydrocyanic acid.[14] The dosage schedule for solid sodium cyanid was followed in the first fumigation with liquid gas, but it was soon found that a revision was needed, to give increased dosages for large, tall trees. Accordingly, a schedule specially revised for liquid gas was prepared (Fig. 19 and Table 6), and this schedule has been successfully followed for two seasons in liquid-gas fumigation in California. Each unit of dosage in this schedule is based on a delivery of 18 cubic centimeters of liquid hydrocyanic acid, 95 to 98 per cent pure, in the form of a very fine spray beneath the tented tree. Thus a tree 30 feet over by 40 feet around calls for 11 charges of 18 cubic centimeters (198 cubic centimeters). By graduating the applicator used in generating the gas in numbers corresponding to those on the schedule, and providing that each

---

[13] Woglum, R. S. A dosage schedule for citrus fumigation with liquid hydrocyanic acid. *In* Journ. Econ. Ent., v. 12, no. 5, p. 357–363, 1919.

[14] Quayle (Univ. Calif. Agr. Expt. Sta. Bul. 308, p. 407) recommends 20 cubic centimeters as the equivalent of 1 ounce of sodium cyanid.

graduation delivers a charge equal to the number of cubic centimeters of which itself and 18 are the product, this schedule is made equally as practical as former schedules. This schedule has given results equivalent to Schedule 1 for sodium cyanid, and should be substituted for Schedule 1 wherever formerly employed in pot or machine generation.

DISTANCE AROUND IN FEET

DISTANCE OVER IN FEET

	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48		50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
10	2	2	3	3	3															10																10
12	3	3	3	4	4	4	4													12																12
14	3	3	4	4	4	4	5	5												14																14
16	4	4	4	4	5	5	5	5	5	5										16																16
18	4	4	4	5	5	5	5	5	6	6	6	6	6							18																18
					20	22	24	26	28	30	32	34	36	38	40	42	44	46	48		50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
20					5	5	6	6	6	6	6	7	7	7	7	7				20																20
22					5	6	6	6	6	7	7	7	7	7	7	7	8	8		22																22
24					6	6	6	6	7	7	7	7	8	8	8	8	9	9		24																24
26								7	7	7	7	8	8	9	9	9	10	10	10	26	11															26
28									7	7	8	8	9	9	10	10	11	11	11	28	12															28
										30	32	34	36	38	40	42	44	46	48		50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
30										8	8	9	10	10	11	11	12	12	12	30	13	13	14	14	14											30
32											9	10	10	11	12	12	13	13	14	32	14	15	15	15	16	16										32
34												10	11	12	13	13	14	14	15	34	15	16	17	17	17	18	18	18								34
36												11	12	13	14	14	15	15	16	36	17	17	18	18	19	19	20	20	21							36
38													13	14	14	15	16	17	17	38	18	18	19	20	20	21	21	22	22							38
															40	42	44	46	48		50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
40																16	17	18	18	40	19	20	21	21	22	22	23	24	24	25	25					40
42																	18	19	20	42	21	21	22	23	23	24	25	25	26	26	27	28				42
44																		20	21	44	22	23	23	24	25	26	27	27	28	28	29	30	30			44
46																				46	23	24	25	26	27	27	28	29	29	30	31	32	32	33		46
48																				48	24	25	26	27	28	29	30	31	31	32	33	34	34	35	36	48
																					50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
50																				50	25	26	27	28	30	30	31	32	33	34	35	36	36	37	38	50
52																				52				30	31	32	33	34	35	36	37	38	38	39	40	52
54																				54					32	33	35	36	37	38	39	40	40	41	42	54
56																				56						35	36	38	39	40	41	42	42	43	44	56
58																				58						36	38	39	40	41	42	43	44	45	47	58

100% DOSAGE UNIT = 18 CUBIC CENTIMETERS

FIG. 19.—A dosage schedule for citrus-tree fumigation with liquid hydrocyanic acid 95 to 98 per cent pure.

TABLE 6.—*Dosage schedule for citrus-tree fumigation with liquid hydrocyanic acid—same dosages as given in Figure 19, but in special arrangement for copying directly on fumigation tapes.*

[Top figures represent distance around. The italic figures under each "distance around" represent distances over trees and the roman figures contain the dosages.]

12	14	16	18	20	22	24	26	28	30	32	34
10—2	*10*—2	*10*—3	*10*—3	*10*—3	*12*—4	*12*—4	*14*—5	*16*—5	*16*—5	*18*—6	*18*— 6
12—3	*12*—3	*12*—3	*12*—4	*12*—4	*14*—4	*14*—5	*16*—5	*18*—6	*18*—6	*20*—6	*20*— 7
14—3	*14*—3	*14*—4	*14*—4	*14*—4	*16*—5	*16*—5	*18*—5	*20*—6	*20*—6	*22*—7	*22*— 7
16—4	*16*—4	*16*—4	*16*—4	*16*—5	*18*—5	*18*—5	*20*—6	*22*—6	*22*—7	*24*—7	*24*— 7
18—4	*18*—4	*18*—4	*18*—5	*18*—5	*20*—5	*20*—6	*22*—6	*24*—7	*24*—7	*26*—7	*26*— 8
				20—5	*22*—6	*22*—6	*24*—6	*26*—7	*26*—7	*28*—8	*28*— 8
				22—5	*24*—6	*24*—6	*26*—7	*28*—7	*28*—7	*30*—8	*30*— 9
				24—6					*30*—8	*32*—9	*32*—10
											34—10
											36—11

TABLE 6.—*Dosage schedule for citrus-tree fumigation, with liquid hydrocyanic acid*—Continued.

36	38	40	42	44	46	48	50	52	54	56
18— 6	20— 7	20— 7	20— 7	22— 8	22— 8	26—10	26—11	30—13	30—14	30—14
20— 7	22— 7	22— 7	22— 7	24— 9	24— 9	28—11	28—12	32—15	32—15	32—15
22— 7	24— 8	24— 8	24— 8	26—10	26—10	30—12	30—13	34—16	34—17	34—17
24— 8	26— 9	26— 9	26— 9	28—11	28—11	32—14	32—14	36—17	36—18	36—18
26— 8	28— 9	28—10	28—10	30—12	30—12	34—15	34—15	38—18	38—19	38—20
28— 9	30—10	30—11	30—11	32—13	32—13	36—16	36—17	40—20	40—21	40—21
30—10	32—11	32—12	32—12	34—14	34—14	38—17	38—18	42—21	42—22	42—23
32—10	34—12	34—13	34—13	36—15	36—15	40—18	40—19	44—23	44—23	44—24
34—11	36—13	36—14	36—14	38—16	38—17	42—20	42—21	46—24	46—25	46—26
36—12	38—14	38—14	38—15	40—17	40—18	44—21	44—22	48—25	48—26	48—27
38—13			40—16	42—18	42—19		46—23	50—26	50—27	50—28
					44—20		48—24			52—30
							50—25			

58	60	62	64	66	68	70	72	74	76	78
30—14	32—16	34—18	34—18	36—21	40—25	40—25	42—28	44—30	46—33	48—36
32—16	34—18	36—20	36—20	38—22	42—26	42—27	44—30	46—32	48—35	50—38
34—17	36—19	38—21	38—22	40—24	44—28	44—29	46—32	48—34	50—37	52—40
36—19	38—21	40—23	40—24	42—26	46—30	46—31	48—34	50—36	52—39	54—42
38—20	40—22	42—25	42—25	44—28	48—32	48—33	50—36	52—38	54—41	56—44
40—22	42—24	44—27	44—27	46—29	50—34	50—35	52—38	54—40	56—43	58—47
42—23	44—26	46—28	46—29	48—31	52—36	52—37	54—40	56—42	58—45	
44—25	46—27	48—30	48—31	50—33	54—38	54—39	56—42	58—44		
46—27	48—29	50—31	50—32	52—35	56—40	56—41	58—43			
48—28	50—30	52—33	52—34	54—37	58—41	58—42				
50—30	52—32	54—35	54—36	56—39						
52—31	54—33	56—36	56—38	58—40						
54—32	56—35	58—38	58—39							
	58—36									

The first applicators for liquid gas had fixed dosage plates. Subsequently the writer's suggestion of detachable dosage plates,[15] each to correspond to a special schedule, was adopted, and all applicators now are equipped with a set of plates the graduations on which represent 14, 16, 18, 20, and 22 cubic centimeter units, or 77, 88, 100, 111, and 122 per cent schedules.

FUMIGATION PROCEDURE.

HOW TO MEASURE THE TREES.

As was stated in the preceding section, the dosage for a tented tree is based on the distance over the top and the distance around the bottom. The distance over the top of a tree is measured easily with a tapeline, but a much better and quicker method is to mark the tent as described previously. When such a marked tent is centered over a tree, the distance over the top is obtained by adding the two numbers that show where the line over the top of the tree touches the ground on opposite sides.

In tenting trees, especially small ones, the center of the tent frequently will fall to one side of the center of the tree, and in such instances one of the auxiliary lines is used. To avoid confusion, the center line should be heavier than the other two. The distance around the tent is taken by means of a tapeline, and can be measured by one man if the tape be provided with a catch for attachment to

[15] Woglum, R. S. Practical fumigation with liquid hydrocyanic acid. *In* Calif. Citrograph, v. 4, no. 10, p. 284, 1919.

the tent. This measurement should be taken about 3 feet above the ground. **Never guess the distance around by pacing.**

SPECIAL SCHEDULE TAPES.

In 1920 a special tape was developed on which dosages were stamped at 2-foot intervals. An example of this marking is shown in Figure 20. The distance around the tree is indicated by the large numerals. The column of figures at the left indicates distances over the top and that at the right indicates dosage. These tapes were widely used in California in 1921. They do away with schedule cards, expedite dosage calculation, and tend toward greater accuracy. If the tape is marked on both sides, but with the numbering starting from opposite ends, the ends can be alternated as one tree after another is measured. Dosage tapes can be made for either cyanid or liquid gas schedules. A schedule of liquid gas dosages in form for copying on tapes is shown in Table 6.

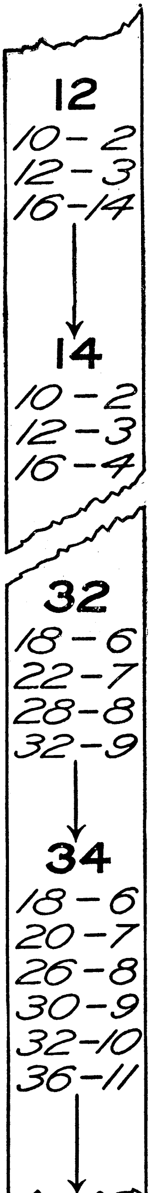


Fig. 20.—Showing method of marking the dosage on a fumigation tape. Large numbers represent distance around in feet; left-hand column represents distance over the tree; right-hand column, the dosage. (Liquid-gas schedule.)

HOW TO COVER THE TREES.

Commercial fumigators usually require that the soil in the orchard shall have been cultivated recently, so that it will be loose and level before the work of fumigation is begun, thus permitting the tents to lie smooth and close to the ground. One tent is then spread on the ground on the side of each tree, in the first row to be treated, farthest from the center of the orchard.

For covering trees up to 18 or 20 feet in height, two poles of the character described on page 5 are required, one for each side of the tree. Preferably, the poles should be about a foot longer than the height of the trees. If rings are attached to the tents the ends of the poles are inserted into the rings. Some fumigators do not use rings on tents manipulated by poles, but double lap the edge of the tent over the end of the pole and attach it by a half hitch of the pulling rope (Fig. 21). This is done quickly, does not subject the tent to undue wear, prevents detachment, which sometimes occurs with rings, and allows

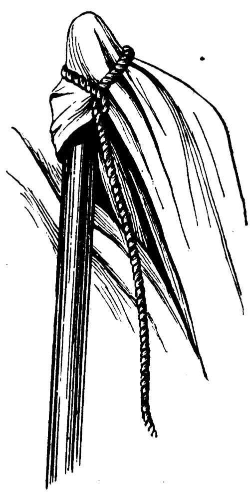
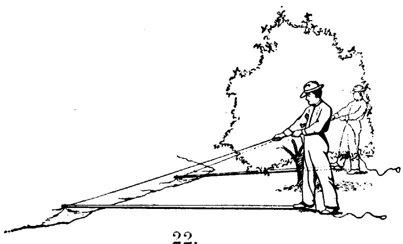


Fig. 21.—Method of attaching tent to hoisting pole by a half hitch of the rope.

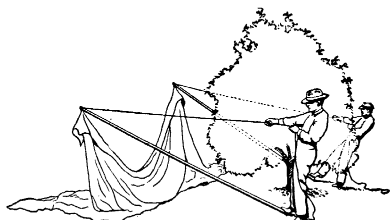
the distance between the poles to be varied in accordance with the width of the tree. **To prevent the seams from pulling apart, the tent always should be moved in the direction in which the strips run.**

The successive stages in covering a tree are shown in Figures 22 to 25. The tent should be held taut between the ends of the poles to prevent it from catching in the top of the tree by sagging. When the covering is completed the poles are detached and carried to the next tree to be covered.

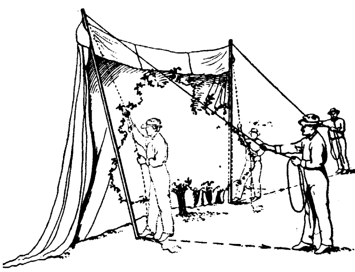
Great care should be exercised in covering large trees to avoid overpulling the tent. The bottom of the tent should be kicked in and, at the same time, examined to see that it lies close to the ground the entire distance around the tree. Where possible, it is much easier to transfer a tent from tree to tree without pulling it to the



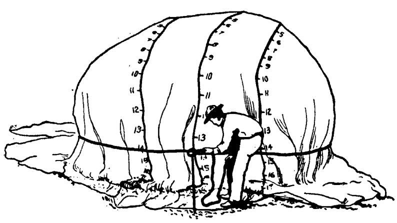
22.



23.



24.



25.

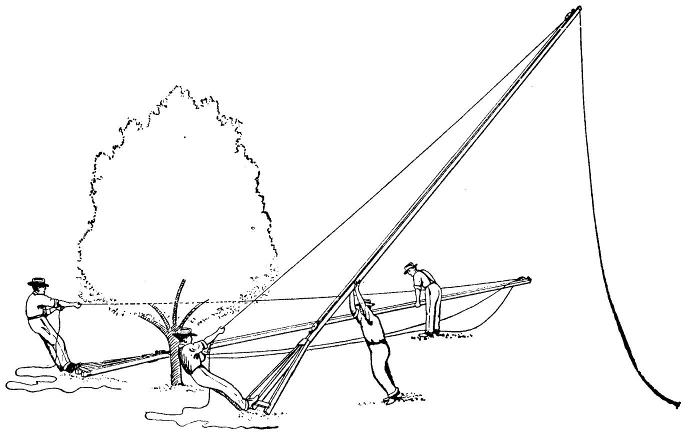
FIGS. 22–25.—Successive stages in placing a tent over a tree with poles.

ground. The poles should be attached to the edge of the tent, then raised and leaned against the tented tree. The remaining steps are the same as those previously explained.

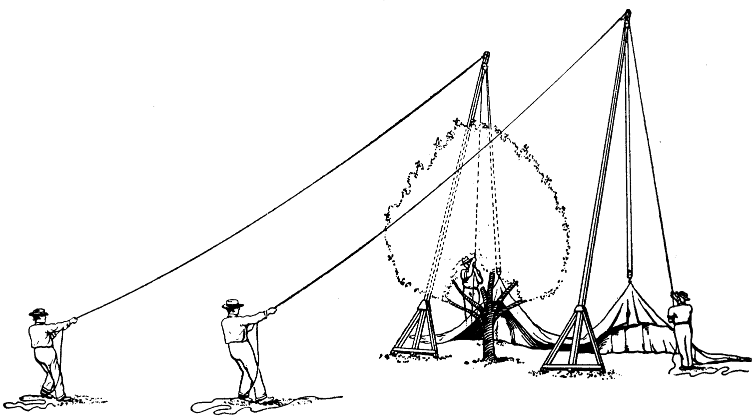
To cover very large trees derricks similar to that shown in Figure 3 should be used. Four men are required for their manipulation. (See Figs. 26 to 28.)

OPERATION OF AN OUTFIT.

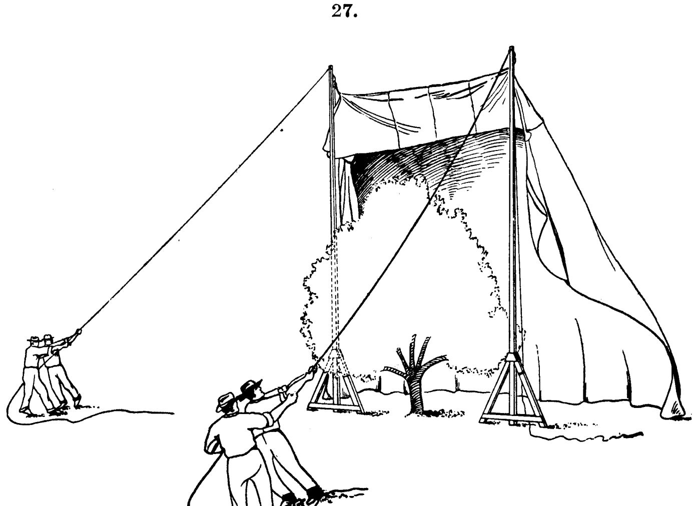
The number of men required to operate a fumigation outfit depends upon the size and number of tents. Two men will handle a large string of 30-foot tents on small trees coverable without poles, although some managers prefer three men for the same work. Large strings of 36 to 43 foot tents require a four-man crew—two pullers, a foreman, and a generator. Outfits of 45-foot tents and upward are usually operated by six men, including four pullers. These figures apply to liquid gas and fumigating machine crews; under the pot system an additional man is required for generating (Fig. 11).



26.



27.



28.

FIGS. 26–28.—Successive stages in placing a tent over a tree by means of derricks.

For many years 30 tents were considered the proper number for an outfit, and two pullers moved the tents. In recent years, with higher labor costs and constantly increasing acreage to be fumigated, the tendency has been to put on four pullers, speed up the work, and increase the number of tents to the limit movable within a one-hour exposure. The average outfit is 45 to 70 tents, but as many as 80 to 90 tents have been manipulated by one six-man crew under ideal weather and orchard conditions.

Each outfit has a foreman, whose duties include supervision of preparation for the night's work and proper direction of the actual field operations. The foreman should be a careful, experienced fumigator. Some managers have the foreman act as generator, but preferably he should be the tape man, a position from which he can closely watch both the pullers and generator.

The first step in fumigation procedure is to cover the trees, and this is closely followed by calculation and application of the dosage. The careful foreman will keep the pullers two to three trees ahead of the generator throughout the row, and the progress should be consistent rather than irregular. The tendency of pullers to hasten toward the end of a row shortens the exposure and should not be permitted. At the finish of a row the crew returns to the commissary and preparations are made for the next row. When using the fumigating machine the residue is emptied outside the grove before refilling. With the pots care must be taken to place them well in toward the trunk, so that any spattering of acid during the generation of gas will not reach the cloth. The man handling the acid should never touch the tents. The residue should always be emptied away from the tree trunks and distant from the tents. The capacity of the fumigating machine or liquid-gas applicator is sometimes inadequate for the entire row and thus requires a refill before the finish. In such cases an auxiliary supply of cyanid solution or liquid gas should be placed toward the middle of the row. A record should be kept of the time each row is fumigated, of the temperature, humidity, wind, sunshine, and the dosage for each tree. The type of chart in common use for this purpose is shown in Figure 29.

Hour started.	Temp. W. S.	Hum. tent damp.	Row.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
			1																				
			2																				
			3																				
			4																				
			5																				

FIG. 29.—Field chart for recording the dosage given each tree and the weather conditions, temperature, humidity, sunshine (s), wind (w), and whether or not tents are damp. On opposite side of chart should be noted the orchard, date, dosage schedule, system of fumigation, insect, amount of material used, number of trees, direction tents are moved and foreman.

CARE OF TENTS.

Tents often become wet at night, particularly late in the season. Wet tents should be avoided in fumigating. Then, too, long-continued dampness tends to weaken the fabric. Wet tents should be spread out on the ground after the last throw. If the trees are large and closely set it might be well for a day man to go over the tents to spread out the folds. After rains tents should be turned until dried. Tents should never be left without attention throughout long-continued rainy periods, but should frequently be moved to prevent mildew. The best way to dry out very wet tents is to draw them halfway over trees. This practice can not be recommended

TIME CARD.

Foreman..............................	Date..............................
Grove..............................	Amt. material..............................
Trees..............................	Method..............................
Size tents..............................	Throws..............................

NAME.	OPERATION.	HOURS—TREES.	CASH.

FIG. 30.—A daily time card to record the work of each fumigation crew.

during very hot weather but is of common occurrence in California during the cooler season.

One of the greatest necessities, and at the same time the one most likely to escape notice, is the proper repairing of fumigation tents. If acid comes in contact with a tent, a hole is certain to be the result, and even with very careful operators acid holes are occurring constantly. These become very numerous if not attended to, and permit leakage of gas. Moreover, tears in tents are of frequent occurrence.

Every large outfit should employ a man to overhaul tents and keep them in the best possible state of repair. This man should be supplied with a sewing machine adapted to tent mending. Tents are best patched by sewing pieces of canvas over the holes, rather than

by trying to draw holes together with threads. Patches stuck by rubber tissue are temporarily satisfactory, but are not lasting, and for this reason are inferior to those machine-sewed. Some fumigators mend tents in the field, while others send them to the warehouse for repairs. When tents are new they probably are most economically repaired at the warehouse, but when old and needing overhauling every few days the repair man should have his sewing machine in the field. Pullers should be constantly on the watch for tears, and when detected the condition and tent number can be noted on the daily report of the foreman (Fig. 30). All tents should be numbered. At the close of the season tents should be thoroughly dried, carefully gone over, and repaired, rolled, and then stored in a closed building having a floor elevated above the ground (Fig. 31). When the centers of tents are worn out before the skirts, or vice versa, it is not necessary to discard the entire tent, but the cloth of good quality can be made into tents of smaller sizes.

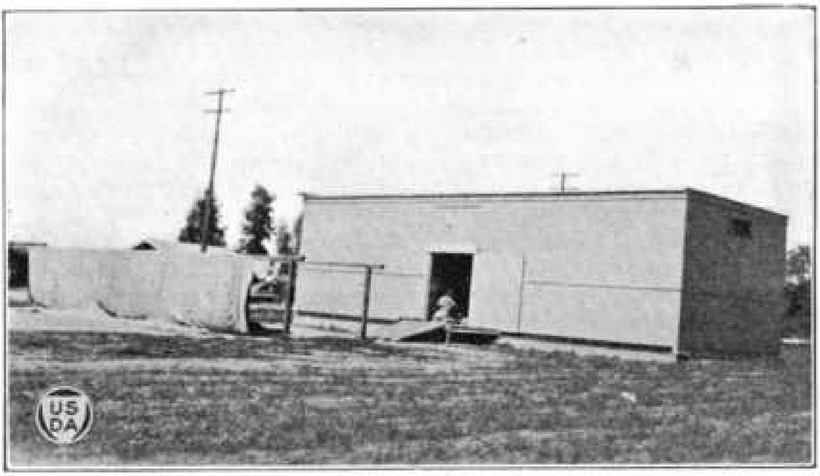


FIG. 31.—Standards for spreading tents to be examined in process of overhauling. The building is used for storing tents.

NECESSITY FOR CAREFUL WORKERS.

Unsatisfactory fumigation is frequently the direct result of carelessness, and for fumigating an orchard it is of primary importance to have careful, conscientious men. It is very easy for a careless scheduler to form the habit of guessing the dosage rather than measuring the trees, for the careless man with the supply wagon to make mistakes in weighing the chemicals, for the generator to go through the motion of dosing the last few trees in a row although the supply of chemicals in the machine is exhausted, or not to trouble himself with testing the applicator although apparently out of order, and for the tent pullers not to kick in the skirts of the tents or pull down the sides which do not touch the ground. The reliable foreman will aim toward effective fumigation and give the fullest attention to details. Furthermore, he will not condone negligence in the other members of the crew. The foreman is really the keystone or pivot man in high-class work. Every effort should be made to employ

experienced, reliable men and to retain such foremen from year to year. Unfortunately, a large number of dependable men are lost every year, owing doubtless in large part to the short season and method of employment. Employment on a monthly salary might well supplant the customary tree or hour basis, and an attempt should be made to retain foremen in some permanent position outside the fumigation season. In recent years there has been a strong tendency for growers to organize into cooperative fumigation associations and employ a competent, well-trained man at a regular salary to take charge of all their pest-control activities.

GENERAL CAUTIONS.

Hydrocyanic-acid gas is one of the most deadly gases known. Therefore precautions in its use are essential. The careful fumigator who avoids being subjected to strong fumes, however, runs no risk. In California men work around tented trees where they breathe diluted gas every night for several consecutive weeks without feeling any ill effects aside from an occasional dizziness or headache. Cyanid should be kept in containers tightly locked while not in use.

Hydrocyanic-acid gas is inflammable, and care should be exercised not to permit the concentrated gas as it rises from the generator to come in contact with fire; diluted gas is not inflammable.

Liquid hydrocyanic acid is far more dangerous than solid cyanid or cyanid solution. Several fatalities have occurred since the introduction of liquid gas and a noticeable increase in the number of cases of people temporarily overcome. The liquid is most active at high temperatures and should always be stored under cool conditions, and in the field protected from the sunshine. The greatest care is necessary in opening a drum, especially when the gas is boiling and pressure has developed. When suddenly uncapped the liquid might spout upward. A safety valve on every drum would reduce the present hazard. It is advisable for two men to be present when a drum of gas is handled or an applicator filled. The tape man should always keep a watchful eye on the generator. A small bottle of ammonia should be in the pocket of every fumigator. When a man is overcome, place ammonia at the nostrils and encourage respiration by the prone pressure method of resuscitation.[16] Never use exposed flames near liquid gas. For close-up work about drums or the applicator an electric flash is safe and convenient.

BOX TENTS.

Gas-tight boxes have come into use in California for small trees and several such outfits have carried on fumigation in districts where small trees are most numerous. The dosage required for these gas-tight boxes is less than half that needed for canvas tents, but the manipulation of the boxes is decidedly more laborious than that of the ordinary covers. The type of box shown in Figure 32 has proved most popular. It is built in sections and is collapsible.

[16] Anybody not familiar with the prone pressure method of resuscitation should apply to the Bureau of Mines, Department of the Interior, Washington, D. C., for a circular which illustrates and describes this method.

The number of sections is increased or decreased as necessitated by the size of the trees to be fumigated. The results in scale kill appear to be more uniform than with common tents.

EFFECT OF THE GAS ON THE PLANT.[17]

Hydrocyanic-acid gas is fatal to insects when the dose is sufficiently large and the exposure long enough, but a much greater strength of gas is necessary for the destruction of some insects than for others. Were it not for the destructive action of the gas on the plants, its field of usefulness would be increased greatly. Since different species and varieties of plants vary remarkably in their power to withstand the poison, however, it is necessary in fumigating with this gas to take into consideration the particular plants to be fumigated and their susceptibility to gas injury.

The foliage and branches of orange, lemon, and grapefruit trees will stand without severe injury a strength of gas sufficient to destroy

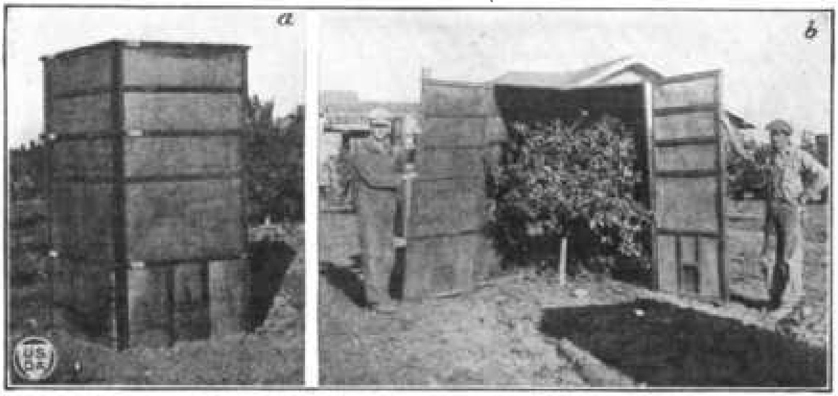


FIG. 32.—A gas-tight box tent for covering small trees. Constructed in sections to make 3, 4, or 5-sided boxes. *a*, Closed; *b*, opened.

most of the scale insects which infest them. Apple, peach, pear, and other deciduous trees in dormant condition can be fumigated without injury with a strength of gas greater than it would be advisable to use on citrus fruit trees.

It is impossible to fumigate a citrus tree effectively without burning back for a few inches many of the tenderest shoots. Slight burning of the foliage, however, is not considered injurious to the trees. The injury to be avoided is the burning and pitting of fruit, and this frequently occurs unless great care is exercised.

The action of hydrocyanic-acid gas on the plant cells is the cause of fruit burning as well as foliage injury in fumigation. Numerous factors, explained later, serve to intensify the injury, but these factors are distinct from the main cause.

The tenderest shoots of plants are the ones most easily injured by this gas. It is well known that a very heavy dosage in field fumigation will not only pit full-grown fruit but even destroy the old

[17] For comprehensive treatment of this subject, see Bull. 907, U. S. Department of Agriculture, 1920.

resistant foliage. Plants in dormant condition are more resistant to gas than are those in their period of growth. When fruit is small and tender it is easily pitted by a moderate strength of gas, whereas the same concentration applied when the fruit has matured may produce no injury at all. The epidermis and the cells immediately beneath in immature fruit seem to be much more susceptible to injury from gas penetration than those in mature fruit.

GAS INJURY THROUGH ABRASION OR PUNCTURING OF THE SKIN OF FRUIT.

It is of common occurrence to see injured fruit in the very tops of fumigated trees When both tents and fruit are dry severe injury is infrequent, but should either or both become very wet severe injury might follow. Especially is this true after fumigation in damp weather on loose, sandy soil. Damp tents collect sand, and when drawn over the trees scrape the fruit, causing abrasions of the epidermis. Once the epidermis is abrased and the cells beneath exposed, the absorption of the gas apparently intensifies the injury, which spreads and usually results in the collapse of a considerable area of skin. These spots are called pits or burns and do not show for from one to three days after fumigation.

Where trees are fumigated under ideal conditions and some fruit is pitted, a close inspection will reveal that many of these pits are in places where the fruit has been abrased by contact with tents, poles, branches of the tree, or other fruit. If the poles are placed well in toward the tree so that they scrape or throw about branches or fruit in covering, abrased fruit sometimes results, especially in damp weather. The tents weigh down the branches and move them more or less severely during the covering of a tree. Where fruit comes sharply in contact with the ragged edge of a branch abrasion of skin is likely to follow. A heavy wind which beats the branches about will also cause much abrasion. Moist weather intensifies this condition. Sometimes, in separating fruit on a cluster after fumigation, pits are found at points of contact. This might be due to weakness of the epidermis, the resut of one fruit brushing against another, or insect attack, which is frequently localized in such protected places. In certain cases insects which frequent citrus trees unquestionably play an important part in pitting. Fruit injured by fumigation has been seen which, at the time of treatment or shortly previous, was severely infested with mites or red spiders. A heavy defoliation of red-spider infested trees was of common occurrence from fumigation during the season of 1920.

Unless the skin has been abrased or weakened shortly before the treatment, well-grown fruit on healthy citrus trees is seldom injured by the average dosage applied under proper weather conditions.

CONDITIONS OF WEATHER DURING WHICH GAS INJURY IS LIKELY TO RESULT.

Unfavorable weather conditions at the time of fumigation are often responsible for injury to trees and fruit. In the following paragraphs various meteorological elements are discussed briefly.

LIGHT.

Fumigation is carried on largely at night. The actinic rays of light intensify plant injury both during and immediately after fumigation. Plants fumigated in direct sunshine or exposed to direct sunshine within one or two hours after treatment are especially subject to injury, the degree depending upon the strength of gas used, the length of exposure, and the temperature of the air. Plants fumigated in diffused light appear to be no more injured than those fumigated in darkness.

During hot summer weather fumigation is performed at night, but as the season advances and the days become cooler the time of starting is extended so that work is commenced before the sun has set. With the advent of winter and dormant trees fumigation may be safely started on cool days early in the afternoon, provided the dosage is not excessive.

Daylight fumigation with pot or machine-generated gas should not be attempted on hot, sunshiny days, or even on cool, sunshiny days during the growing season. Although daylight work has been successfully performed with field-generated gas on warm days through reduction of dosage and length of exposure, the method is too hazardous, in view of the present state of knowledge, to be recommended. The limitations for liquid hydrocyanic acid are less restricted than for pot or machine-generated gas.

Since liquid hydrocyanic acid has come to be used in fumigation, daylight practice is no longer considered a dangerous experiment. During the winter months outfits operate throughout the daytime in bright sunshine, in many cases with complete safety and under conditions which in the past with pot or machine generated gas were wont to produce severe injury. Outside of possible differences in physical properties of the gas due to the method of generation and application, the one most plausible reason for the increased safety of daylight operation is the difference in diffusion throughout the tree. In pot-generated gas the greatest concentration is toward the tree top, the point of maximum temperature, whereas with the liquid hydrocyanic acid in warm weather the greatest concentration is toward the bottom of the tree. One fumigator in California now operates exclusively in the daylight with liquid gas and has worked out a sliding scale of dosages and exposures for the different temperatures. As compared with night fumigation, the dosages are only slightly reduced, but the length of exposure during the growing season approximates not more than one-half the usual night exposure, or 25 to 35 minutes. In daylight work particular attention is given to the season of the year, the soil condition, general health of trees, and topography of the land. Although enough daylight work has been carried on in California to show that operation with liquid gas in the sunlight is practicable under certain conditions, the limitations of these conditions have not yet been sufficiently established for a fumigator safely to attempt daylight work during the growing season without extended personal experience in that particular locality. Temperature and sunshine intensity are primary factors to consider, but are not always safe guides. Instances have been noted of more severe injury closely following sunrise than during the afternoon

at much higher temperatures. Then there is a marked difference in the susceptibility of different varieties. Navels appear to withstand sunshine fumigation with liquid gas a little better than Valencias, but lemons are far more resistant than either; in fact, the dosage can be materially increased and the exposure lengthened on lemons without damage. The fumigation of lemons in the sunshine with dosages of 110 and even 120 per cent schedules for one hour with apparent safety has been observed in different parts of southern California during the winter season. However, the dosage system for winter daylight fumigation followed by several California fumigators with considerable success approximates the following: At temperatures below 65° F. a 110 per cent dosage for lemons and 100 per cent for oranges, exposure 40 minutes. At temperatures from 65° to 75° the exposure is often shortened to 35 minutes. On cool days after midafternoon the dosage is increased 10 per cent over the above figures or the exposures lengthened.

Sunshine fumigation at low humidity appears more to be feared than at high humidities.

The injury characteristic of daylight fumigation is severe leaf drop on the sunward side of the tree. Fruit is seldom injured. When fruit injury occurs it is commonly a bleach or burn on the sun-exposed surface—seldom the pitting which so often characterizes night fumigation injury.

TEMPERATURE.

Heat.—Temperature exerts one of the most important modifying influences on injury from fumigation. The actual temperature during the treatment is not the only heat influence, but the temperature after the exposure directly influences the result and also that before the exposure, but to a much less extent. Very little injury appears to result from the heat factor alone at temperatures upward to 70° to 75° F. with the schedules commonly used, but it is well to hold these temperatures as the maximum for general work. At certain seasons of the year, particularly in some sections, it has been found safe to fumigate well above 70° F. Fumigation in the citrus districts of central California during July and August is started at temperatures as high as 85° F. without injury. This safety at high temperatures is largely attributable to the hardened or resistant condition of the trees, brought about by long-continued exposure to a hot, dry summer climate. Fumigation at such high temperatures in the more humid coastal districts where trees are physiologically active throughout the summer would be apt to produce severe injury. Humidity influences in some degree high-temperature fumigation. This is well illustrated by fumigation in some coastal districts. While it is ordinarily unsafe to operate there above 70° F. it has been found that during protracted periods of warm, dry weather work could be started at 75° F. with safety. Furthermore, in the hotter, interior valleys of southern California the general temperatures at which fumigation is carried on are considerably higher than nearer the coast. Winter work, particularly with liquid gas, has been performed by some fumigators at temperatures upward to 80° F. In daylight fumigation the temperature is of primary consideration and should in large part guide the dosage.

Cold.—Experience has shown that fumigating trees at a temperature near the freezing point often results in severe injury. In some

instances treatment has been carried on with impunity at a freezing temperature, but the risk is too great to justify such treatment of citrus fruit trees. It is recommended that all fumigation be discontinued when the temperature drops to 38° F.

It has been noted that fumigation on nights when the temperature fell below freezing sometimes produced severe injury to trees dosed at temperatures as high as 40° or 42° F. a few hours prior to freezing. Therefore it would appear advisable on nights when frost warnings are sent out to stop fumigation at 45° F. Undoubtedly humidity has a very direct bearing on the temperature at which injury occurs. The results of some California fumigators indicate that the most dangerous nights are when the humidity is low and the wind from the north. It is on such nights that temperature drops are most sudden. A high degree of moisture in the air tends to check a rapid drop in temperature and to protect the fruit from freezing. Fruit injured from fumigation at too low temperatures takes on a scalded appearance, loosens at the buttons, and drops within a few days following the treatment. There may be a complete shedding of fruit without noticeable leaf injury.

Where liquid gas is applied as a vapor, most fumigators consider it generally less effective at low temperatures and advocate that work be stopped at temperatures lower than 50° F., others place 45° as the limit. while a few fumigate with liquid gas to 40°.

WINDS.

Fumigation should never be attempted during heavy winds for two reasons: First, the gas is blown out of the tent, so that poor work results; second, injury to trees may occur. The burning of fruit and the dropping of foliage during heavy winds have been observed frequently. One fumigator who checked his entire season's work reported results during even a slight breeze decidedly poorer than when calm. A safe guide to follow is to discontinue fumigation as soon as the wind is sufficiently strong to cause the tents to flap. In California there are winds called locally "Santa Ana," or "electric," which are the result of storms in the surrounding desert, and fumigation during these periods is especially to be avoided, as they are accompanied usually by high temperatures and low humidity.

MOISTURE.

Although hydrocyanic-acid gas in the presence of water readily passes into solution, it has been proved definitely that the presence of water alone on citrus trees, even in excessive amounts, is in no way responsible for burning by possible absorption of gas.

There are other reasons of an indirect and largely mechanical nature, however, which necessitate the consideration of moisture. (1) The presence of moisture increases the weight of the tents, rendering them more difficult to handle, which results in much injury to fruit and branches. (2) On light, sandy soil, damp tents collect much dirt and injure fruit by scraping when being pulled over trees. (3) Moisture affects the fiber of the cloth, rendering it more impervious to gas; a wet tent becomes almost gas tight. Therefore in fumigating large trees on a damp night more gas accumulates in the tops of the tents than is normally the case. This intense strength of

gas sometimes causes pitting, especially with varieties least resistant to hydrocyanic-acid gas.

Doubtless the chief cause of fruit injury is the action of hydrocyanic-acid gas on skin abrasions produced by covering the tree with wet, heavy tents. Entire rows of trees have been seen in which fully half of the fruit had been rendered worthless from severe gas burning at tent-scraped surfaces. Considering the disadvantages and resultant injury in the use of wet tents, it is evident that fumigation should be discontinued as soon as the leaves and fruit become thoroughly moist.

Air moisture, or humidity, is one of the principal factors which make fumigation less safe near the coast than in the warmer interior valleys. The low humidity in the interior tends to harden the trees and also keeps the tents dry, while near the coast the high humidity has the opposite effect. The increased gas-holding qualities of damp tents and the corresponding increased injury to trees fumigated with such tents have led to attempts to avoid this injury by reducing the dosage as the humidity rises above a certain point. It has not proved entirely practicable to work out a sliding dosage schedule based on humidity alone. Tents sometimes become very wet at a relative humidity of 88 to 90, whereas on other nights tents will remain dry at a humidity even as high as 93. Any humidity chart that does not take cognizance of the actual condition of the tent is not likely to be broadly adopted. The presence of moisture on trees does not appear to reduce the efficacy of hydrocyanic-acid gas against scale insects. Such gas absorption as occurs is more than offset by the reduced leakage through the damp tents; in fact, when tents become really damp some fumigators have followed the practice of reducing the dosage 10 per cent to avoid increased injury, it being maintained that the scale kill equals that with the higher dosage and dry tents.

Although it has been stated that the greatest influence of humidity during fumigation was through its action on the tenting by increasing or decreasing its gas tightness, it appears at times to have also a direct influence on injury. At temperatures below 40° F. it appears that a humidity of 50 or 60 is far more dangerous than a humidity of 90, particularly if the temperature later in the night drops below 32° F. At high temperatures explanations of the humidity factor usually end with the monosyllable "if." In Tulare County fumigation is carried on for weeks with almost complete absence of burning at humidities usually ranging from 35 to 70, yet later in the season with higher humidity injury is frequent. In Orange County with humidity ranging from 60 to 100 injury is most prevalent at 88 and above when the tents become damp. The exceptions to this condition are periods of very low humidity, 0 to 40, especially when these dry periods follow periods of high humidity. Such weather in southern California is usually accompanied by desert storms, and the air appears surcharged with electricity. Fumigation at such times is sometimes followed by very severe injury, particularly the pitting and burning of fruit, and the safest policy is to discontinue all operations until the weather becomes more settled. One indication of especially treacherous fumigation weather is fluctuation of the temperature over several degrees, accompanied by puffs of warm air.

With gas-tight covers moisture produces results inferior to those accomplished under dry conditions. A very dilute gas is used with gas-tight covers. Apparently absorption of gas by the moisture further dilutes the gas.

EFFECTS OF FUMIGATION ON UNHEALTHY TREES.

Occasionally a part or all of an orchard is composed of trees weakened by lack of such essential treatments as proper cultivation, fertilization, or irrigation. Many orchards contain trees weakened by attacks of gum disease, scale insects, gophers, and numerous other agents which check their normal development. These unhealthy trees are more susceptible to injury from fumigation than are perfectly healthy ones, and a dosage which in no way would affect a perfectly healthy plant is likely to cause pitting of fruit and shedding of leaves.

INFLUENCE OF SOIL CONDITIONS ON FUMIGATION INJURY.

The moisture conditions surrounding growing plants have been shown to influence their development and susceptibility to injury from fumigation, those growing under moist conditions being less resistant to gas than those growing under dry conditions. The mere wetness of the soil does not in itself offer full explanation of plant injury due to this factor. For instance, the fumigation of orchard trees immediately following a heavy rain has been done with no more injury than to trees in dry soil. Likewise, fumigation frequently follows immediately after an irrigation without noticeable damage to the trees. The writer believes that the greater injury to citrus trees in wet soil comes from changes in foliage or fruit induced from being subjected to a very moist condition for a sufficiently long period to make them less resistant to hydrocyanic acid. This position is supported by the results of soil investigators to the effect that soil moisture in excess of the optimum leads to depressed growth, light-colored foliage, and general lack of vigor, the visible damage being greater than if the moisture condition is below the optimum. It is often noted in fumigation on sloping or rolling ground that trees in the swales, low spots, or so-called wet spots are more subject to injury than those on the higher ground. Instances of severe leaf drop following the fumigation of trees near leaky irrigation stands have been reported. Although a dry soil tends to slacken growth and hasten maturity of plants, thereby rendering them more resistant to hydrocyanic acid, it has been observed that protracted situation in soil so deficient in moisture that the plant suffers ultimately leads to a physiologically weakened condition. It has been stated elsewhere in this bulletin that plants in a state of impaired health are more susceptible to injury than normal healthy plants.

The soil type also appears so to influence the physiological condition of the tree that modified reaction to hydrocyanic acid sometimes occurs. A 30-acre lemon orchard which was fumigated experimentally in 1918 was about equally divided between two distinct soil types, one a loam designated as a "barren" soil, the other black adobe which contained about 10 per cent humus. Injury occurred

throughout this orchard, but the degree was noticeably greater on the loam than on the black adobe. Other instances of injury due to different soil types have been noted. Groups of trees whose growth has not kept pace with the rest of an orchard, owing possibly to inferior subsoil, to hardpan, gravel, etc., are not uncommon. Trees under such adverse conditions have sometimes been more adversely affected by fumigation than healthier trees.

Plants best resist cyanid gas if in a hardened or dormant condition at the time of fumigation. Hardening is brought about either by cold weather or by a dry soil. Since citrus is mostly grown in countries that practice irrigation, the dryness of the soil can be regulated by regulating irrigation. As a general rule, therefore, fumigation should precede the run of water rather than follow, as is frequently the practice at the present time.

STRENGTH OF GAS CITRUS TREES WILL STAND WITHOUT INJURY.

The lemon tree is much more resistant to injury from fumigation than is the orange or grapefruit and seldom suffers appreciable damage when treated under normal conditions with either Schedule No. 1 or the three-fourths schedule. Some varieties of oranges are injured more easily than others. Of the varieties of commercial importance in California, the Navel and Valencia are the least susceptible to injury from gas treatment. The seedling is almost equally hardy, while the tangerine (mandarin) stands the gas quite well. The Mediterranean Sweet is not quite so resistant to the gas as are the preceding varieties, and the Homosassa and St. Michael are easily injured by fumigation. It is inviting damage to fumigate the last two varieties with Schedule No. 1, and injury might result with the three-fourths schedule unless prevailing conditions were favorable. Fortunately, the Navel, the Valencia, and seedlings comprise the bulk of the oranges grown in this State.

In general a strength of gas up to the three-fourths schedule, and in some districts Schedule No. 1, can be used on citrus trees with a minimum amount of injury if care be exercised. In Tulare County a 110 per cent schedule is safely used, except at the start of the season. This same schedule is sometimes used in the interior valleys of southern California toward the close of the season. In recent years, with increased resistance of some scales, dosages of 125 per cent strength have come into practice. Such high dosages have been found unsafe on oranges during the growing season unless the exposure is shortened.

As fruit on the tree matures its resistance to gas injury increases. Fruit in transport or in storage appears to be more resistant to gas injury than fruit on the tree.

FUMIGATION INJURY TO SPRAYED TREES.

Orange trees frequently are sprayed for the control of certain insect pests or plant diseases. The sprays in common use are Bordeaux mixture, lime-sulphur solution, and petroleum oils. If trees are fumigated after the application of Bordeaux mixture, injury will result, especially during damp weather. The most characteristic type of injury is defoliation, and this is often accompanied by severe

fruit pitting. (Fig. 33.) Although it is for the most part safe to fumigate six months after spraying, injury has been noted in a few cases as late as 11 months after the spray was applied. Injury after such an extended period, however, appears to be brought about by very heavy dosages, wet tents, weak trees, or possibly an excessive use of strong Bordeaux. It is a common practice in California to spray the lower branches of citrus trees and the ground in the late autumn or winter to prevent brown-rot of the fruit. Where such spraying is done it should follow fumigation, not precede it. Furthermore, at least two or three days should elapse before a fumigated orchard is sprayed with Bordeaux mixture in order to allow the tree time to recover entirely from the shock of fumigation. The injury in the case of trees sprayed only at the

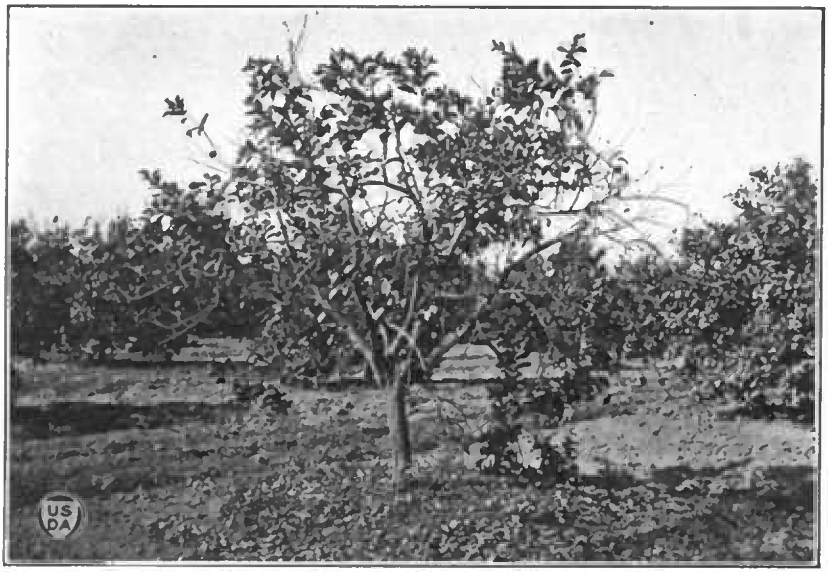


FIG. 33.—A lemon tree defoliated from fumigation following spraying with Bordeaux mixture. Entire tree sprayed in January and fumigated with 110 per cent schedule the following September.

bottom is not necessarily confined to the sprayed part, and many cases have been recorded where trees fumigated from a few days to a few months after the spraying were almost completely defoliated, in sprayed as well as unsprayed portions. Such defoliation has been decidedly more pronounced with orange trees than with lemons. Where conditions arise in the case of skirt-sprayed lemons which convince the grower that he can not afford to delay fumigation for six months after the Bordeaux application, the injury risk can be greatly reduced by avoiding daylight work, by avoiding strong dosages, and by fumigating at low humidities (not over 85) with thoroughly dry tents.

The trunks and branches of citrus trees are painted with Bordeaux paste to cure certain gum diseases. Where only the main trunk is painted, fumigation is usually performed with safety at any

time, even immediately after the treatment. Particularly is this true of lemon trees, and very seldom has a trunk-painted lemon been injured unless the tree was very young or severely scraped before the Bordeaux application. Valencia trees are most susceptible of all varieties, and some cases of severe injury have been observed from the Bordeaux being washed by rains into the soil and entering the tree through the root system. There is considerable risk of severe damage from fumigation, particularly with oranges, where the trunk painting is extended well up into the branches, or where the branches alone are coated. The basis of this trouble is probably the copper in the Bordeaux paste, for copper readily combines with cyanid in a very toxic compound. The copper might be absorbed through the foliage or tender bark or taken up by the roots if washed into the soil. The risk of fumigation injury has induced some growers to discontinue the use of Bordeaux above the main trunk in favor of certain carbolineum or creolineum preparations which do not react with cyanid gas; in fact some growers use these latter materials exclusively for treating diseased trunks, as well as branches and roots. It appears that Bordeaux-treated trees are more susceptible to injury from daylight work than from night fumigation.

Recently some fumigation tents of green cloth which had been mildew-proofed by a copper salt were introduced into California. These tents when new injured the trees in a manner typical of Bordeaux effects.

Trees previously treated with an oil or sulphur spray can be fumigated without injury other than that which might occur on unsprayed trees. If the trees are weakened by the use of oil sprays, however, fumigation may cause leaf drop.

UNEXPLAINED INJURY.

Probably the most unsatisfactory part of fumigation to grower and fumigator is diagnosing cases of injury. Most of the factors which bear on this problem have been stated, but when considered as a whole they are somewhat confusing and not always tangible. Furthermore, injury frequently occurs, the causes of which can not be fully explained. This unexplained injury further confuses the situation. Numerous cases of unexplained injury occurred on October 13 and 14, 1921, when orchards in widely separated districts of southern California were severely damaged from fumigation. Other treated orchards in the same districts were uninjured. The damage, which amounted for the most part to leaf drop, continued throughout the night. The weather appeared well suited to fumigation. For several years it has been noted that there is a period during the last part of October and early November when fruit pitting is of frequent occurrence—decidedly more frequent than in work either before or after this time. During 1921 this condition was so pronounced in some districts, particularly toward the coast, as seriously to interfere with the progress of the work. While it is believed that the period of susceptibility to fumigation corresponds with certain physiological changes within the trees, nothing sufficiently tangible has been developed to make possible avoidance of the injury. There are periods of the year when dry desert winds blow over the citrus districts of southern California, and the air

often appears surcharged with electricity. Fumigation at such periods sometimes leads to severe injury; at other times, under practically identical conditions, no injury occurs. Cases have been reported where severe injury followed fumigation immediately preceding a heavy rainstorm, yet there are innumerable cases of fumigation before a rain without any injury whatsoever. Fruit pitting might be of common occurrence in one orchard, although an adjacent one treated at the same time was uninjured. Difference in physiological conditions of the trees or in soil relations which might explain the injury are not sufficiently tangible to satisfy the average grower whose fruit is injured.

Some fumigators believe that fruit pitting is sometimes more pronounced in pot or machine fumigation than in liquid-gas work. On the other hand, foliage injury sometimes is more severe in liquid-gas work with the applicator than where a warm gas is supplied from the pot, fumigating machine, or vaporizer.

FUMIGATION OF TREES IN BLOOM.

Ordinarily the blossom growth is quite resistant to fumigation and work can be conducted with safety right up until the petals fall. There have been seasons, however, when the blossom growth, particularly on Valencias, appeared to be quite susceptible to injury for a period commencing when the growth was about a half inch long up to the time the blossoms were well formed. When fumigating with strong dosages during the bloom, therefore, give careful attention to the effect of the gas during this susceptible period, and if severe burning occurs discontinue work until the blossoms are well developed and in a condition when they will withstand the gas treatment. The bloom on lemons is decidedly more resistant to fumigation than that on oranges and is seldom seriously injured at any time of year.

CITRUS INSECTS AND THEIR CONTROL.

CITRUS PESTS AGAINST WHICH ORCHARD FUMIGATION MAY BE PRACTICED.

Fumigation with hydrocyanic-acid gas is especially adapted to the control of scale insects and white flies, which live a part or all of their existence attached to the plants, and, as practiced at the present time, orchard fumigation is confined almost exclusively to the control of this class of insects on citrus fruit trees.

DIRECTIONS FOR CONTROLLING VARIOUS CITRUS PESTS.

Much experimental work with fumigation against various citrus pests in California and Florida has resulted in definite records of the successful control of these insects. Insects such as the white flies and armored scales, which can be destroyed in practically all stages of development, can be fumigated at any time the trees are in a condition best fitted to resist injury. In general, soft or unarmored scales are very resistant to hydrocyanic-acid gas in the mature and egg stages; it is advisable, therefore, to fumigate these pests during their breeding season while the insects are in the immature stages.

Black scale.[18]—The black scale has been developing resistance to fumigation in some localities. A decade ago it was readily controlled anywhere in California in the immature stages by the use of a three-fourths (75 per cent) schedule. To-day this strength of gas has little effect on the scale in some important districts. This has led to the more or less general practice in recent years of applying as heavy a dosage as the trees will safely stand. The preferred method is to start the season with an 85 per cent dosage and raise to 100 per cent (No. 1) as soon as possible. In districts where 100 per cent is too low, the dosage should be raised to 110 or even 120 per cent late in the season. A 110 per cent dosage is probably about the limit which orange trees will stand, except when hardened by cold weather. A 100 per cent schedule appears to be about the limit of safety during the growing season on oranges in the coastal districts. Most fumigation for the black scale is done from August to December. In some localities toward the coast this scale insect is somewhat irregular in development and best reached by fumigation in July or during the winter months. The exposure should be one hour.

Red scale.[19]—The red scale, like the black scale, is also developing immunity to fumigation in some localities. The three-fourths or 75 per cent schedule which cleared the trees of this pest a few years ago is now effective only in a few interior districts. In parts of Riverside and Orange Counties dosages even as high as 125 per cent have not given thorough satisfaction, and sometimes two fumigations a year are required. Although the red scale is susceptible to cyanid gas at any time of the year, in these districts of resistant scale it appears preferable to delay fumigation until winter, December to March, if possible, when a much heavier dosage can be safely used. Lemon trees will then usually withstand a 125 per cent dosage for 45 minutes or 1 hour. Some fumigators have used a dosage as high as 150 per cent on lemons for 30 to 40 minutes and report good results. A dosage of 110 per cent is usually the limit on oranges. Red-scale control by fumigation can not be considered entirely satisfactory in some districts.

Purple scale.[20]—A 100 per cent schedule is required for thoroughly effective results against the purple scale. In warm weather an 85 per cent schedule has proved fairly satisfactory. A good practice is to start the season with an 85 per cent schedule and increase to 100 as soon as the fruit develops resistance to the gas. Never use less than an 85 per cent schedule for this insect. The best season to fumigate is August to December. Never fumigate for the purple scale during the winter, for at this season the eggs are very difficult to destroy. Exposure should last for one hour.

Citricola scale.[21]—Start the season with 85 per cent dosage and increase to 100 or even 110 per cent as soon as possible for the citricola scale. Fumigation for this scale is most successful in July and August. Satisfactory work can sometimes be done the first part of September. Late autumn or winter fumigation against this pest has proved unsatisfactory. Exposure should last from 45 minutes to 1 hour.

---

[18] *Saissetia oleae* Bern.
[19] *Chrysomphalus aurantii* Mask.
[20] *Lepidosaphes beckii* Newm.
[21] *Coccus citricola* Camp.

Yellow scale.[22]—Use 88 to 100 per cent schedule for 45 minutes. Fumigate at any time of year. If winter fumigation is done use 100 or 110 per cent dosage.

White flies[23] **and Florida red scale.**[24]—Start with 85 per cent dosage and raise to 100 per cent as soon as possible. Fumigate in Florida from December to February. Expose 45 minutes to 1 hour. Daylight work with liquid gas might prove to be the most successful method in Florida through avoiding the high humidity more or less prevalent at night.

LENGTH OF EXPOSURE.

In fumigation with untreated cloth tents practically all of the gas escapes before the expiration of one hour unless the weather is very damp. Experience in orchard fumigation has shown that an exposure of 45 minutes for most insects gives practically as good results as that of an hour. Where eggs are present, the one-hour exposure results in slightly more effective work.

TIME OF YEAR FOR FUMIGATION.

Many of the scale insects can be destroyed easily by fumigation at any stage of development. These insects may be fumigated at any time of the year, and include such species as the red, yellow, and purple scales. Other scale insects are very resistant to treatment in the egg and adult stages. This type of insect, which includes such species as the black, hemispherical, and soft brown scales, must be treated in the early stages of development, when they are least resistant to the gas.

Unfortunately, citrus trees are not in a condition to resist gas injury equally well at all times of the year, and care must be used to see that fumigation is carried on under the most favorable weather conditions and when the fruit is of fair size. It is preferable, of course, to fumigate after the fruit has been picked, but this is seldom possible in California. The principal season for orchard treatment in California is from the 15th of July to the middle of December; in Florida the season most suited for fumigation would appear to occur between the first of December and the end of February, the approximate period of tree dormancy and minimum rainfall.

REMOVAL OF OLD SCALY FRUIT.

Scale insects on fruit are usually more difficult to destroy than those on the leaves or branches. Especially is this true for an egg-laying species such as the purple scale. When fruit is picked, a few old scaly oranges are occasionally left on the trees. Such fruit should be removed before fumigation, lest it become a source of reinfestation after the other parts of the tree have been cleaned.

SUCCESSIVE TREATMENTS.

As stated, some scale insects are very resistant to fumigation in the egg and adult stages, though easily destroyed in the immature stages. Occasionally plants which will not stand a high concentration of gas

---

[22] *Chrysomphalus citrinus* Coq.
[23] *Aleyrodes* spp.
[24] *Chrysomphalus aonidum* L.

are infested with all stages of scale insects, and if the eggs and adults are very resistant it is possible to control the pest through the destruction of the immature insects by using a concentration of gas which will not injure the plants. In such cases successive fumigations are necessary; the first will destroy all the immature insects present at the time of treatment, and fumigations repeated at the necessary intervals will destroy all the insects hatching since the preceding fumigation. This work necessitates a knowledge of the life history of the insect concerned.

COOPERATIVE FUMIGATION.

In California there are three systems of fumigation: (1) The contract system, under which parties having one or more fumigation outfits contract with growers to do their work at a certain amount per tree; (2) private ownership, where owners of large groves do their own fumigation work; and (3) cooperative fumigation.

Throughout California citrus-fruit growers are organized into cooperative associations for handling their fruit, which is marketed through a central organization, the California Fruit Growers' Exchange. Many of these local associations own and operate their own fumigation outfits for the benefit of their members. In recent years the tendency of growers to handle their own fumigation has led to the formation of large cooperative fumigation companies, which include the members of several citrus associations. These cooperative companies are formed by the growers in a community getting together and agreeing in writing to finance the project. A board of directors is elected and plans made for a capital stock organization. Each acre of orchard coming in is assessed a certain amount of stock. With the first companies this was $5 an acre, but experience has proved $10 or $15 an acre a more workable basis. Part of the stock is paid in cash, and the balance by an annual tax on each box of citrus fruit produced by the orchard. If a sufficiently large acreage joins to make it a going concern the company is organized and a manager of recognized ability is selected to run the business. Cooperative fumigation has been a big success, and the extent of the success has been directly in proportion to the ability of the manager. Copy of a typical contract between the grower and the fumigation company follows:

I, the undersigned, hereby subscribe for and agree to buy, take and pay for ------------------ shares of capital stock of the Orange County Fumigation Company, a corporation, at the price of $1.00 per share, par value, and herewith tender the one-tenth part of the purchase price thereof; the remainder of the purchase price thereof to be paid at the rate of one cent per packed box of citrus fruits produced from the property for which stock is issued, including current packing season, which one cent per box, the Manager of ------------- --------------- Association is authorized to pay the Orange County Fumigation Company until such stock is fully paid up, provided, however, that at least an additional one-tenth of the purchase price of said stock shall be paid each year, including the current year, until said stock is fully paid.

By this subscription I am subscribing for sufficient of said stock so that with stock, if any, already owned or subscribed for by me in said corporation I will become the owner of ten shares of said stock for every seventy-five trees or fractional part thereof of citrus fruits owned by me upon which service by this corporation is desired. The provisions of this subscription contract shall be construed with any other subscription heretofore made by me so as to require

the payment of an aggregate of one cent per said packed box to be applied on the purchase price of all stock so subscribed for, with a minimum payment of one-tenth of said price.

____

Subscriber.

RESPONSIBILITY FOR FUMIGATION INJURY.

Leaf-drop and fruit injury occur to a greater or less extent every fumigation season. When the crop damage is severe the grower may be inclined to place the responsibility for the damage on the fumigator, particularly if he considers that the fumigator employed inexperienced help or that the work was carelessly done. The causes for fumigation injury are in many cases so elastic and so little understood that the adjustment of injury complaints to the mutual satisfaction of the grower and fumigator is seldom obtained. Cyanid gas is toxic to plant life, and in citrus trees injury sometimes occurs even when a 75 per cent schedule, the minimum for orchard fumigation, is employed. As the dosage is increased above this point the risk from injury is correspondingly greater. Most scale pests require a dosage approximating a 100 per cent schedule if they are to be effectively controlled; in some districts an even higher dosage is necessary. These high dosages mean that fumigators are operating most of the time in the danger zone. When the weather is right and the trees in a physiological condition resistant to cyanid gas, work progresses with little trouble. This is normal to most fumigation. When, however, serious injury occurs and the responsibility must be determined, the question arises, "Did the injury result from inexperience and negligent methods employed by the fumigator or is it attributable to causes which were to all intents and purposes unavoidable, beyond the control of the operator, and happened in spite of his efforts to do a careful, effective job?" If the damage can be attributed to negligent methods, the fumigator is in part or wholly responsible. If the fumigator possessed a working knowledge of the principles of fumigation and performed his work carefully and with due regard to the generally observed rules, then injury, should it occur, must be considered as one of the hazards of the work and be borne by the grower, unless the fumigator voluntarily decides to make an adjustment. Fumigation at freezing temperatures, at very high temperatures, in a strong wind, when the tents are very wet, and guessing at the dosage instead of measuring—all constitute careless fumigation. Injury from a heavy dosage employed by the fumigator in an effort to do a satisfactory job can scarcely be considered negligence, unless the dosage was well above any used in other orchards in that particular district and was done without the prior understanding or consent of the grower.

COST OF FUMIGATION.

The cost of fumigating an orchard depends primarily upon the size of the trees and the dosage rate used. Trees 1 to 3 years old which can be covered with 30-foot tents may not cost more than 20 cents each to fumigate, whereas large seedlings often cost $1 to $1.25 each. One large California citrus ranch of 600 acres expended

$17,000 for fumigation in 1921. The average citrus orchardist in California expends $25 to $40 per acre for one fumigation treatment, or an average of 35 to 45 cents per tree. The cost to the grower is usually based on three factors, namely, covering, chemicals, and drayage. The covering cost for 45-foot tents in 1921 averaged 20 cents per tree. The factory cost for liquid hydrocyanic acid was 70 cents per pound, but many fumigators charged the growers 75 cents, the extra 5 cents to cover hauling and loss of material. Solid sodium cyanid is usually 35 cents a pound, this cost to include all the sulphuric acid necessary to generate the cyanid and hauling the chemicals to the field. This charge applies alike to pot and fumigation machine. Cooperative fumigation companies base their charge to growers on approximate cost. This cost includes such items as chemicals, labor, drayage, and overhead (tent rent), the latter to include depreciation of equipment, repairs, insurance, and administration. Most concerns figure tent depreciation on a five-year turnover. Depreciation is frequently lumped with other overhead costs, including labor, and all included in a tree-basis assessment. The figures in Table 7, which are the combined averages of several large companies owning a wide range of tents, should prove helpful to new organizations in arranging a program of costs. These figures are averages of both coast and interior fumigation, handled on a large scale. Concerns operating during the dry season in the interior valleys, or whose work is confined largely to medium-sized or small trees, should cover a larger number in a season than the figures given in the table indicate, and thereby have slightly lower depreciation costs per tree. Where a concern has only a few large tents for covering a small number of scattering large trees the depreciation per tree covered will be high. In such cases a common practice is to make the small sizes help pay for the depreciation of the large sizes.

TABLE 7.—*Tent depreciation, general overhead, and labor costs for fumigation on a tree basis.*

[The figures are averages based on the experience of several large California fumigation concerns.]

Tent size.	Cost of tent.	Average number of trees covered by one tent each year.	Cost per tree.		
			Tent depreciation.	Depreciation and other overhead.	Labor.
36	$38	450	$0.02	$0.065	$0.06
42	56	400	.03	.08	.07
45	60	350	.035	.095	.09
48	72	300	.05	.11	.125
52	85	225	.075	.15	.155
60	112	200	.115	.20	(1)

1 By hour.

One fumigation concern has decided that a cost of $3.20 per acre for 36's and $4.20 an acre for 45's will cover depreciation, mending, and drayage. Ten per cent of the total bill is charged, in this case, for administration. Some large companies report a cost per tree of

about 4 cents for general overhead expenses. The labor of most outfits works on a tree basis, the foreman receiving about one-half cent per tree more than the other members of the crew. Where operating on a per hour basis the average hourly wage for pullers during 1921 was about 70 cents and for the foreman 85 cents. It is customary to allow 50 cents a man for the roll up of tents at the completion of each job. Some concerns pay 25 cents a man for the last pull off of tents each night.

The cost of the total equipment for an outfit of sixty 45-foot tents on the basis of 1921–22 prices ranged between $3,600 and $4,500. The fumigation equipment required to handle 1,500 to 2,000 acres in some of the older citrus sections of California (approximately three hundred and twenty-five 36 to 60 foot tents, truck and trailer, and other necessary equipment) will approximate $25,000 to $30,000. The total cost during the season of 1921 for fumigation in California was almost $3,000,000, or a tax of approximately 3 per cent on the $83,000,000 citrus crop.

FUNDAMENTALS FOR SUCCESSFUL FUMIGATION.

Trees should be measured, not guessed, and dosed according to standard schedule.

A careful, experienced foreman is the keystone to safe, effective fumigation.

Use heavy dosages. Start with an 85 per cent schedule, if possible. Raise to 100 per cent as soon as the trees will stand the heavier dosage.

Fumigation during even a moderate wind tends toward poor results and is advised against.

It is poor policy to fumigate orchards heavy in cover crop.

All equipment should be kept in good repair.

Tents should be centered on trees, kicked in to hang perpendicular from the outer limbs, and the edges touch the ground all around.

It is well to keep records of individual tree dosage, temperature, humidity, and time of start and finish.

SCALES.

Black scale.—Fumigate the scale when in its youngest stages of development. The season usually extends from August to December, some coastwise orchards excepted. Use 85 to 100 per cent dosage for one hour. Resistant-type scale requires even more concentrated gas. If double fumigation is practiced, the second treatment should follow the first in two or three months.

Red scale.—From the middle of December to April is the preferred season to fumigate for the resistant red scale. The schedule commonly used on lemons is 125 per cent; on oranges, 100 to 110 per cent. The ordinary red scale can be fumigated at any time of year with an 85 to 100 per cent schedule. An exposure of 45 minutes to one hour should be given.

Citricola scale.—Fumigate during July or August with the 100 per cent schedule, and during the first part of September with the 110 per cent schedule, if possible. Do not fumigate later than the middle of September.

Purple scale.—Use 100 per cent dosage, if possible; never less than 85 per cent. Expose the trees one hour. Do not fumigate during the winter.

Fumigation of black or purple scales at temperatures near the freezing point often results in poorer scale kill than at higher temperatures.

FUMIGATING MACHINE.

Test the fumigating machine for accuracy two or three times a week.

Stir the cyanid solution in the solution tank before using.

Before fumigating a row, generate 2-ounce charges until the machine is filled with gas.

Cyanid solution will crystallize at temperatures around 40° F.

The same dosage schedule is used for the fumigating machine as for pots.

For liquid gas a slightly different schedule is used in which the dosage for large trees is somewhat increased.

LIQUID HYDROCYANIC ACID.

Liquid hydrocyanic acid is inflammable. Keep open flames at a distance from drums or applicators.

Inspect and test applicators for accuracy every day before starting work.

Direct the nozzles of applicators away from the trunks of small trees to avoid injury.

The nozzles of applicators should not be placed among weeds or cover crop, and should be within the foliage fringe of the tree.

Results from atomized liquid gas appear to be most satisfactory at warm temperatures. Preferably it should be used at temperatures above 50° F.

Vaporized liquid gas gives a better diffusion within the tent than when atomized through a nozzle.

Eighteen cubic centimeters of high-purity liquid gas is equivalent to 1 ounce of sodium cyanid for scale kill under field conditions.

INJURY.

Avoid fumigating trees sprayed with Bordeaux mixture, or painted with Bordeaux paste high above the trunks, within 6 to 10 months after application. If done at a shorter interval, fumigate only at low humidity and with dry tents.

Fumigation with pots or fumigating machine should be stopped at 36° F. on damp nights; and on dry nights, when frost warnings indicate that the temperature is likely to fall to freezing or below, complete safety demands stopping at 43° to 45° F.

Fumigation with wet tents often is the cause of severe injury. Work should be stopped when tents become wet.

Sunshine is one of the most harmful agents to plants in connection with fumigation. It exerts an influence both during and after the treatment. Safe sunlight fumigation requires a proper knowledge of dosage, exposure, and temperature influences. Without this knowledge daylight fumigation should not be attempted.

In the coastwise districts it is generally unsafe to fumigate above 75° F. In hot interior districts, where the trees harden in summer, work appears to be carried on with safety even as high as 85° F.

Sulphuric acid will burn canvas. Care should be exercised, therefore, to avoid the residue from fumigating machine or pots coming into contact with the tents.

Fumigation during periods of desert or "electric" winds sometimes produces severe fruit injury.

Trees in bloom can be fumigated with safety with moderate dosages.

Fumigation should precede rather than follow an irrigation.

Hydrocyanic acid is one of the most deadly gases known. Particular care should be exercised in handling liquid gas. Two men should always be present when filling the machine. Drums should not stand exposed to hot sunshine. Each man should be furnished with a small bottle of ammonia for use in case one of the crew is overcome. At least two men on each crew should be familiar with the prone pressure method of resuscitation.

COUNTY REGULATIONS GOVERNING FUMIGATORS OPERATING IN SOUTHERN CALIFORNIA, 1922–23.

REQUIREMENTS.

All fumigating tents shall be marked in accordance with the Morrill system.

The foreman of each fumigating crew shall be equipped with a thermometer properly tested within the range of 28° to 100° F. (See recommendation No. 8.)

All equipment used by fumigators shall be kept in good repair when in use.

No pump for liquid-gas applications shall be operated having more than 3 per cent variation from correct measurement.

Each tent shall be placed so that one line of numerals runs over center of top of tree.

Tents shall be kicked in to hang perpendicularly from outer limbs of tree to ground, and shall touch the ground on all sides.

Work must not be carried on when wind is strong enough to cause any appreciable movement of tent walls.

Each tree requiring more than a four-unit charge shall be taped and correct dosage given as called for upon chart.

Trees shall be given not less than 45 minutes' exposure regardless of dosage, and work of tent pullers shall be regulated accordingly.

Trees shall not be fumigated with pots or cyanofumer when temperature is below 37° F.

Trees shall not be fumigated with liquid gas when temperature is below 50° F.

Work shall be discontinued when tents begin to become damp.

Deviation except by the grower's consent from any of the foregoing requirements will be considered sufficient ground for the revocation of crew foreman's license or contractor's license and certificate to operate.

Each fumigator shall submit on the first of each month a report to the county horticultural commissioner showing for each piece of work performed during the previous month: Date, grower's name, location of orchard, number of orange or lemon trees, kind of material used, and strength.

Fumigator shall keep on file and furnish upon request of horticultural commissioner statement of amount of material used on any piece of work.

A chart of each orchard shall be made and kept on file for one year, showing the dosage given each tree and the temperature and time at the beginning of each set. A copy of this chart shall be furnished the grower or county horticultural commissioner upon request.

Carelessness in application of materials or other evidence of abuse of privilege to do business under license or certificate shall at all times constitute grounds for revocation of same.

RECOMMENDATIONS.

1. A written contract between grower and fumigator is recommended. Any deviation from the above requirements authorized by the grower should be mentioned therein.

2. There is considerable danger of tree injury at high temperatures. The danger point is reached in coastal districts near 75° to 80° F. and in interior districts near 80° to 85° F.

3. Daylight fumigation is not recommended at any time except as generally practiced beginning late in afternoon under most favorable cloudy conditions.

4. Care should be taken not to allow containers of liquid gas to become heated. Keep them in a shady place and keep covered with wet sacks.

5. Leakage from liquid-gas containers is extremely harmful to tree roots, and care should be taken to keep containers far enough from trees to insure safety.

6. Residue from pots or cyanofumer should be dumped far enough from trees to prevent damage.

7. Operators must bear in mind that many people are not aware of the dangerous properties of the materials used in fumigation, and every possible precaution should be taken to guard against accidents. Containers of cyanide or acid in any form should be locked or covered in such a way that the contents can not be released by children or irresponsible persons.

8. The United States Bureau of Standards, Washington, D. C., and the department of meteorology of the Los Angeles Chamber of Commerce, 800 Central Building, are properly equipped to test thermometers. The seal and certificate of either of these offices will be accepted. A nominal fee is charged for this service.

9. All tents should be numbered serially on at least two sides with black numerals not less than 4 inches in height.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE.

Secretary of Agriculture	HENRY C. WALLACE.
Assistant Secretary	C. W. PUGSLEY.
Director of Scientific Work	E. D. BALL.
Director of Regulatory Work	
Weather Bureau	CHARLES F. MARVIN, *Chief.*
Bureau of Agricultural Economics	HENRY C. TAYLOR, *Chief.*
Bureau of Animal Industry	JOHN R. MOHLER, *Chief.*
Bureau of Plant Industry	WILLIAM A. TAYLOR, *Chief.*
Forest Service	W. B. GREELEY, *Chief.*
Bureau of Chemistry	WALTER G. CAMPBELL, *Acting Chief.*
Bureau of Soils	MILTON WHITNEY, *Chief.*
Bureau of Entomology	L. O. HOWARD, *Chief.*
Bureau of Biological Survey	E. W. NELSON, *Chief.*
Bureau of Public Roads	THOMAS H. MACDONALD, *Chief.*
Fixed-Nitrogen Research Laboratory	F. G. COTTRELL, *Director.*
Division of Accounts and Disbursements	A. ZAPPONE, *Chief.*
Division of Publications	EDWIN C. POWELL, *Acting Chief.*
Library	CLARIBEL R. BARNETT, *Librarian.*
States Relations Service	A. C. TRUE, *Director.*
Federal Horticultural Board	C. L. MARLATT, *Chairman.*
Insecticide and Fungicide Board	J. K. HAYWOOD, *Chairman.*
Packers and Stockyards Administration *Grain Future Trading Act Administration*	CHESTER MORRILL, *Assistant to the Secretary.*
Office of the Solicitor	R. W. WILLIAMS, *Solicitor.*

This bulletin is a contribution from

Bureau of Entomology	L. O. HOWARD, *Chief.*
Fruit Insect Investigations	A. L. QUAINTANCE, *Entomologist in Charge.*

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
10 CENTS PER COPY

▽